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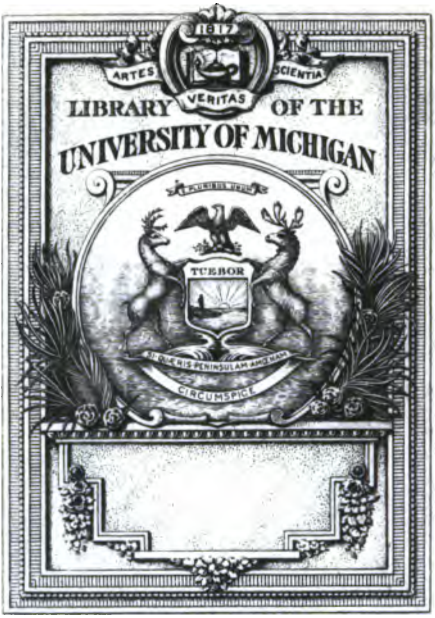

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THE ELEMENTS

OF

CHEMISTRY.

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FOR THE USE OF

Schools, Academies, and Colleges.

BY

ames
EDWIN J. HOUSTON, A.M.,

PROFESSOR OF PHYSICAL GEOGRAPHY AND NATURAL PHILOSOPHY IN THE CENTRAL HIGH
SCHOOL OF PHILADELPHIA; AUTHOR OF "ELEMENTS OF PHYSICAL GEOGRAPHY,"
"ELEMENTS OF NATURAL PHILOSOPHY," ETC., ETC.

PHILADELPHIA:
ELDREDGE & BROTHER,
No. 17 North Seventh Street.
1883.

PREFACE

has been made in this book to present in logical the latest developments of chemical science.

innumerable facts of chemistry, those only have ced that are either of practical importance, or retical value as to be necessary for the elucida- nical theory. By so doing space has been gained tion generally confined to more extensive treatises.

atively extended space has been given to the nature mical force; to the ideas concerning atoms and mole- gaseous combination by volume; to the theory of ies, and to the theory of replacement or substitution, ear conceptions of these principles are essential to any ogress in chemical science.

quantivalence of the elements, and the influence of such ence on the complexity of molecular structure, are impressed on the mind of the student by the roduction of graphic formulæ. With the same rtant reactions are given in full.

een added a chapter on crystallography, in which ypical forms of the different systems, but also the ifications of these forms, as actually occurring in epresented by numerous cuts.

s has been practicable, the non-metallic and the ments have been discussed under classes according uantivalence, a treatment which will, it is hoped, memory in retaining the numerous facts connected

ost difficult department of the science—organic , or the chemistry of the carbon compounds—has

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it is believed, been greatly simplified by the adoption of a classification based on the peculiarities in the linking of the carbon nuclei.

Full explanations are given as to the best method of conducting experiments, and, where necessary, cautions are enforced, so as to avoid accidents to the beginner.

It is hoped that the division of the text into large and small print, and the introduction of the Questions for Review, of the Syllabus, and of the Questions for Examination, will be of practical assistance to the teacher. A copious index has been added to the book.

The author has not hesitated to draw information from all the standard works on chemistry or its allied sciences. He desires particularly to mention his indebtedness to the very complete Treatise on Chemistry by Roscoe and Schorlemmer; to the Organic Chemistry of Adolph Strecker; to the excellent translation of Wurtz's Elements of Chemistry by Dr. Wm. H. Greene, and to the works of Dr. Youmans.

The author is especially indebted to Dr. Wm. H. Greene for revision of the text, and to Dr. Wm. H. Wahl for revision of the proof-sheets of the chapter on Crystallography.

E. J. H.

CENTRAL HIGH SCHOOL,
PHILADELPHIA, August, 1883.

CONTENTS

PART I.

THEORETICAL CHEMISTRY.

CHAPTER I.

PAGE
Introductory. The Nature of the Chemical Force . 13

CHAPTER II.

Theory of Chemical Combinations. Definite and Multiple Proportions. Atomicity and Quantivalence . 24

CHAPTER III.

Theory of Substitution. Chemical Nomenclature . 38

CHAPTER IV.

Combination by Volume. Gay Lussac's Laws. Molecular Volume 48

CHAPTER V.

Crystallography 55

* * *

PART II.

DESCRIPTIVE AND EXPERIMENTAL CHEMISTRY.

THE NON-METALS.

SECTION I.

Hydrogen and the Haloids.

CHAPTER I.

Classification of the Non-Metallic Elements. Hydrogen 68

CHAPTER II.

PAGE
CHLORINE, BROMINE, IODINE, AND FLUORINE 75

SECTION II.

OXYGEN, SULPHUR, SELENIUM, AND TELLURIUM.

CHAPTER III.

OXYGEN AND ITS COMPOUNDS WITH THE PRECEDING ELEMENTS 87

CHAPTER IV.

SULPHUR, SELENIUM, AND TELLURIUM 103

SECTION III.

NITROGEN, PHOSPHORUS, BORON, ARSENIC, ANTIMONY, AND BISMUTH.

CHAPTER V.

NITROGEN 118

CHAPTER VI.

PHOSPHORUS, BORON, ARSENIC, ANTIMONY, AND BISMUTH . 130

SECTION IV.

CARBON AND SILICON.

CHAPTER VII.

CARBON AND SILICON 150

THE METALS.

SECTION I.

INTRODUCTORY.

CHAPTER VIII.

PROPERTIES AND CLASSIFICATION OF THE METALS 175

THE PERISSAD METALS.

SECTION II.

THE MONAD METALS.

CHAPTER IX.

THE METALS OF THE ALKALIES AND SILVER 183

SECTION III.
THE TRIAD AND THE PENTAD METALS.

CHAPTER X.

PAGE
GOLD AND THALLIUM. VANADIUM, COLUMBIUM, AND TANTALUM 203

THE ARTIAD METALS.

SECTION IV.
THE DYAD METALS.

CHAPTER XI.

BARIUM, STRONTIUM, CALCIUM, AND LEAD 211

CHAPTER XII.

THE METALS OF THE EARTHS 230

CHAPTER XIII.

MAGNESIUM. ZINC AND CADMIUM 243

CHAPTER XIV.

MERCURY AND COPPER 251

SECTION V.
THE TETRAD METALS.

CHAPTER XV.

THE METALS OF THE PLATINUM GROUP 266

CHAPTER XVI.

TIN AND TITANIUM 273

SECTION VI.
THE HEXAD METALS.

CHAPTER XVII.

THE METALS OF THE IRON GROUP 281

CHAPTER XVIII.

THE METALS OF THE CHROMIUM GROUP 301

A chemical change is one that cannot take place in a substance without the loss of its specific identity.

If we take a piece of dry hard rubber and rub it briskly over the coat, it acquires the power of attracting and repelling light bodies, that is to say, it becomes electrified. The acquisition of this additional property, however, is not attended with the loss of the properties it originally possessed: its color, hardness, elasticity, etc., remain the same, whether the rubber is electrified or not.

So also a piece of hard iron becomes permanently magnetized by being stroked several times with a sufficiently powerful magnet, and thereby acquires the property of attracting and repelling other magnets, without losing any of the properties that enable us to distinguish it as hard iron.

The changes whereby the rubber becomes electrified, or the iron magnetized, are called physical changes, because they do not cause a loss of the specific identity of the body.

If, however, the rubber be exposed to a sufficiently powerful heat it will be gradually changed into various gaseous substances, none of which resemble the rubber from which they were formed.

So, also, if the iron be exposed to damp air it will gradually become covered with rust, a substance formed by the iron combining with the oxygen of the air. Here an entirely new substance has been formed, that resembles neither the iron nor the oxygen.

The changes seen in the rusting of the iron, or in the decomposition of the rubber, are called chemical changes, because they are attended with a loss of the specific identity of the substances.

4. Physics and Chemistry.—Physics, or natural philosophy, is that branch of science which treats of the physical changes that occur in matter.

Chemistry is that branch of science which treats of the chemical changes that occur in matter.

5. Elementary and Compound Substances.—Elementary substances or elements are those which have never as yet been separated into more than one kind of matter. Gold is an elementary substance. It cannot, by any known means, be separated or broken up into anything else than gold.

Compound substances are those which are formed by the union of two or more elementary substances. Brass is a compound substance, formed by the union of copper and zinc; steel is a compound substance formed of iron and carbon.

It must be carefully borne in mind that it is by no means probable that all the elements are known to us, or that the so-called elementary substances are necessarily composed of but one kind of matter. They are merely such as have thus far resisted all the forces that have been brought to separate them into two or more different kinds of matter. It is quite possible that many of the bodies now believed to be elementary are in reality compounds of some simpler forms of matter, and that we will hereafter be able to separate them into their component parts. In the absence of proof to the contrary, however, we may safely regard them as elements.

6. The Constitution of Matter. Atoms and Molecules.—Investigations that will be shortly explained have led to the belief that all matter is composed of exceedingly small, unalterable particles, that cannot be changed or altered in form, size, or weight, by any known variety of force. These particles are called *atoms*, the word signifying that which cannot be cut or divided.

The atoms are so exceedingly minute that they cannot be seen with the most powerful microscopes. Though invisible, we have good reasons to believe that they are absolutely unalterable—that they cannot be cut, scratched, or abraded, and that they are unaffected in size by heat or any other known force.

All atoms of the same kind of matter have the same weight, but atoms of different kinds of matter have different weights. Any single atom of iron, for example, has exactly the same weight as any other atom of iron, but it has a different weight from an atom of gold, and either of these is still different from an atom of silver.

It is not believed that the atoms, though almost infinitely small, are mere points; they have actual size or magnitude, and perfectly definite weight.

Atoms, both of the same and of different kinds of matter, are attracted towards and combine with one another and form larger masses, called *molecules*. Molecules are elementary or compound.

An elementary molecule is one formed by the union or combination of two or more atoms of the same kind of matter.

A compound molecule is one formed by the union of two or more atoms of different kinds of matter.

The molecules, though necessarily larger than the atoms, are, nevertheless, invisible, even with the most powerful microscopes. The most minute particles of matter we can obtain, by continued division or grinding, are not single molecules, but consist of thousands of cohering molecules.

7. Atomic and Molecular Attractions.—The force that causes the atoms to combine or unite with one another is called the chemical force, or *affinity*.

The molecules are also drawn or attracted towards one another. This attraction exists both between molecules of the same kind, and between molecules of different kinds of matter.

The attraction that exists between molecules of the same kind of matter is called *cohesion*. It is cohesion that binds together the molecules in a mass of iron or steel. Different degrees of cohesive attraction cause the difference in the solid, liquid, and gaseous conditions of matter.

The attraction between unlike molecules, that is between molecules of different kinds of matter, is called *adhesion*. It is the force of adhesion that causes ink to cling to paper, glue to wood, or mortar to stone or bricks.

8. Positions of the Atoms and Molecules in Bodies.—The molecules do not touch one another, even in the densest kinds of matter, but are separated by spaces that are much larger than the size of the molecules. These spaces, like the size of the molecules, are far too small to be visible. When, through the action of heat, matter expands, it is the intermolecular spaces that are enlarged, and not the size of the molecules.

The molecules are in constant motion towards and from one another. These motions increase as the body grows hotter. A body radiates or throws off its heat by means of a wave motion that the molecules, in their movements to and fro, impart to a highly elastic and very mobile substance, called ether, that fills all space, and exists even between the molecules and atoms.

When the mutual attractions between the atoms cause them to combine chemically, it is not believed that they actually touch one another, but that they are also separated by spaces. These spaces are called the *inter-atomic spaces*, in order to distinguish them from the *inter-molecular spaces.*

9. Distinction between Atomic and Molecular Attraction.—If finely divided metallic copper, in the state of filings or otherwise, be thoroughly mixed with pulverized sulphur or brimstone, no chemical combination will occur between them, and no matter how intimate the mixture, there is no loss of their specific identity. However they may appear to the eye, the use of even a moderately weak glass will reveal the separate particles of sulphur and copper; the one with their characteristic yellow color, and the other with their peculiar metallic lustre. If, however, the mass be sufficiently heated, the sulphur combines energetically with the copper; and an entirely new substance is formed, called sulphide of copper, or cuprous sulphide, that resembles neither of its constituent elements. Here two atoms of the copper have combined with one atom of sulphur, and formed an entirely new molecule.

So, also, if lampblack or powdered charcoal be mixed with sulphur, either of the constituents can be readily distinguished; but when combined, an entirely new molecule is formed, called carbon disulphide, consisting of one atom of carbon combined with two atoms of sulphur. This substance, as in the previous example, possesses properties quite different from those of either of its constituents; it is a clear, colorless liquid, having an unpleasant odor.

Since atomic or chemical combination is invariably attended by the formation of a new molecule, it must always cause a loss of the specific identity of the substance or substances so combined.

The change in specific identity caused by atomic combination is very varied; by its influence solids are converted into liquids or gases, and liquids or gases into solids. Colorless constituents form highly colored compounds; scentless elements unite to form delicate perfumes or highly disagreeable odors; while elements, perfectly inocuous in themselves, unite so as to form the deadliest poisons.

When bodies are mixed together so as to merely adhere, they may be readily separated from one another, but when combined chemically they cannot be readily separated. Thus while the carbon and the sulphur are merely mixed together, they may be readily separated by washing in water; but when once united chemically, they cannot be separated without the exertion of a powerful force, such as heat or electricity.

10. Variations in the Intensity of Atomic or Chemical Attraction.—There is a great diversity in the intensity of atomic attraction: in some cases the mutual attractions of the atoms occur with very great intensity; in others they are exceedingly weak. As a rule, the attraction is stronger between unlike atoms than between like atoms.

When carbon is burned in air, it enters into combination with oxygen, and forms a compound in which the carbon atoms are attracted towards the oxygen atoms with very great force. Compounds of this character are called *stable compounds.*

On the other hand, nitrogen, combined in certain proportions with chlorine, forms a compound in which the union of the dissimilar atoms is so feeble that they are explosively separated by a mere touch. Compounds of this character are called *unstable compounds.*

11. Circumstances Influencing Atomic or Chemical Combination.—Chemical attraction is exerted at infinitely small distances only. For the atoms to combine they must come within the sphere of their mutual attractions; consequently, any cause that increases their freedom of motion aids chemical union.

Atomic or chemical combinations are influenced by a variety of circumstances, viz.:

Cohesion.—Since cohesion binds like molecules together, it often opposes chemical combination. In many cases cohesion must first be overcome before chemical union occurs.

A rod of iron held in a gas-flame will not burn; the molecules of the iron are attracted towards one another with greater force than their constituent atoms are attracted towards the surrounding oxygen; but overcome the cohesion by filing the rod, and as the filings fall through the flame they combine with the oxygen in brilliant scintillations.

Solution.—Many substances that will not combine when intimately mixed in a dry state, combine readily when dissolved in water or other liquid that does not act chemically on them. This, as before, is caused by the greater freedom of motion given to the molecules by weakening their cohesive attractions.

Sulphur and iron, when intimately mixed, will not combine chemically in the cold, provided they are quite dry. If, however, they are moistened with water, a gradual combination ensues.

Heat.—The attraction of the atoms for one another is increased by heat. This is because of the greater freedom of motion that an increase of temperature imparts to the molecules, thus enabling their constituent atoms to unite and form new molecules.

As we have already seen, sulphur will not combine in the cold either with copper or carbon, but, when aided by heat, the combination readily occurs.

Since, however, the effect of heat is to cause a vibratory motion of the molecules of the compound substance, as the temperature becomes higher and higher, we can easily see that the motions may at last become so great as to cause the constituent elements to move out of the spheres of their atomic attractions, and thus cause the *decomposition* of the substance.

It would appear in such cases as if the increase of temperature also occasioned a vibratory motion of the atomic constituent of the molecules, and that the decomposition occurs when a certain limit is reached in the motion of the atoms.

Mercury, when heated to near its boiling point in free air, becomes gradually covered with a red powder, due to the union between it and the oxygen of the air; this combination would not occur at ordinary temperatures, since, as is well known, mercury will keep its silvery surface almost indefinitely. Here then the combination is determined by the influence of heat.

The same red powder, however, that has been so formed, will, if heated to a much higher temperature, be decomposed thereby into metallic mercury and gaseous oxygen.

Light.—Like heat, light is capable of influencing both chemical combination and decomposition. Its more general action is in effecting decomposition.

A mixture of chlorine and hydrogen, that will not combine in the dark, combines explosively when exposed to full sunlight.

Certain compounds of silver are readily decomposed by the influence of light. Photography is based on such decompositions.

Carbonic acid, a combination of carbon and oxygen, absorbed by the leaves of plants, is decomposed by the sunlight; the carbon is retained for the production of woody fibre, and the oxygen thrown off.

The fading of such colored fabrics as carpets and curtains, is caused by the decomposition of their coloring matters by the sun's light.

Electricity.—Chemical union is often determined by electricity. An electric spark passed through a mixture of certain gases, such, for example, as oxygen and hydrogen, causes them to enter into combination. Here the spark evidently acts by its heating power, since a flame will produce the same effect.

In the same manner, the more intense heat occasioned by passing a number of sufficiently powerful electric discharges through certain compound gases, will effect their decomposition.

Electricity, however, apart from its heating effects, is a powerful agency in producing both chemical combinations and decompositions. These combinations and decompositions are effected mainly by means of the current developed by the Voltaic pile, as will be explained more fully hereafter.

12. Analysis and Synthesis.—We may ascertain the chemical composition of a substance in two ways; viz., by analysis and by synthesis.

We may decompose the body into its constituent elements; this process is called *analysis*.

Or, we may produce the substance by causing its constituent elements to enter into combination; this process is called *synthesis*.

In analysis, the decomposition may be either partial or complete; thus we may decompose flour into a variety of substances, such as gluten, starch, oil, and water; this process is called *proximate analysis.* Or, we may determine the final elements in these separate bodies; this process is called *ultimate analysis.*

If we simply determine the elementary substances that are present in a compound, the analysis is called *qualitative.* If we determine the relative proportions of these elements, the analysis is called *quantitative.*

◆

SYLLABUS.

Matter is anything which both occupies space and prevents other things from occupying the same space.

The different kinds of matter are called substances.

All substances have certain distinctive properties or peculiarities that characterize them.

The particular group of properties, that enable us to recognize a particular substance, form what is called its specific identity.

The various changes to which matter is subject may all be embraced under two classes; viz., physical and chemical.

A physical change is one that may occur in a substance without the loss of its specific identity. Physical changes affect the molecules only.

A chemical change is one that cannot occur in a substance without the loss of its specific identity. Chemical changes result from the reunion of the atoms.

A piece of rubber when electrified, or a piece of hard iron when magnetized, acquires additional properties without losing those originally possessed. These, therefore, are instances of physical changes.

The rubber, when decomposed by heat, or the iron when rusted, acquires entirely new properties, and loses those originally possessed. These, therefore, are instances of chemical changes.

Natural Philosophy, or Physics, is that branch of science which treats of the physical changes occurring in matter.

Chemistry is that branch of science which treats of the chemical changes occurring in matter.

All substances are either elementary or compound.

Elementary substances, or elements, are those which have never as yet been separated into more than one kind of matter.

Compound substances are those which are formed by the union of two or more simple substances.

It is not certain that all the substances now called elementary are actually such. We may eventually be able to resolve them into simpler parts, by more powerful means of decomposition than those we have already employed.

All matter is composed of exceedingly minute particles called atoms. Though infinitely small, they have actual size and definite weight. They are infinitely hard, and can neither be cut, scratched, nor abraded.

Atoms, both of the same and of different kinds of matter, combine and form masses called molecules. Molecules may be either elementary or compound.

An elementary molecule is one formed by the union of two or more similar atoms. A compound molecule is one formed by the union of two or more dissimilar atoms.

The force that causes the atoms to combine with one another is called the chemical force, or affinity.

Cohesion is the attraction existing between similar molecules. Adhesion is the attraction existing between dissimilar molecules.

Neither the atoms nor the molecules touch one another; they are separated by spaces that are larger than the size of the atoms or the molecules.

Molecular combination, as occurring in adhesion or cohesion, does not alter the specific identity of the substances. Atomic combination is always attended by a loss of the specific identity.

The chemical force that holds the atoms together varies greatly in its intensity, being in some cases very energetic, and in others very feeble.

Chemical attraction is exerted at infinitely small distances only. Its operation is generally aided by any cause that gives greater freedom of motion to the ultimate particles.

Atomic combinations are influenced by the following circumstances, viz., cohesion, solution, heat, light, and electricity.

Heat, light, and electricity may also cause chemical decomposition.

We determine the composition of a compound substance by analysis, when we decompose or separate it into its component parts. We determine its composition by synthesis, when we produce the substance by causing the combination of its elementary constituents.

Qualitative analysis ascertains the kind of elements present in a compound substance; quantitative analysis ascertains the proportions of these elements.

QUESTIONS FOR REVIEW.

Define matter. What two properties must all matter possess? Define substances. Name some of the distinguishing properties that characterize different substances. Define specific identity.

Distinguish between physical and chemical changes. Which of these affect the molecules only? Which affect the atoms only?

Give any examples of physical changes. Give any examples of chemical changes.

Explain in full the difference between Natural Philosophy, or Physics, and Chemistry.

Distinguish between elementary and compound substances, and give some examples of each.

Explain in full what you understand by an atom of matter. Are the atoms visible by means of powerful microscopes? Name some of the properties of atoms.

Have atoms definite size and weight?

What are molecules? How do they differ from atoms? Which are the larger? Why?

What is the difference between an elementary and a compound molecule?

What name is given to the force that causes the combination of the atoms?

Distinguish between adhesion and cohesion. How do cohesion and adhesion differ from chemical affinity?

Do either the atoms or the molecules touch one another in any kind of matter?

What effect is produced by heat on the molecules? Are the molecules ever at rest?

Does either adhesion or cohesion cause a loss of the specific identity of substances? In what respect does this differ from atomic attraction?

Give any instances that show the variations existing in the intensity of atomic attraction.

Distinguish between stable and unstable compounds.

Enumerate the circumstances that influence atomic or chemical combination.

Why should cohesion affect chemical combination? Give an example of such influence.

What effect has solution on chemical combination? Give an example of this effect.

Is it generally an intense or a feeble heat that favors chemical combination? Explain the reason for this circumstance.

Give some instances of chemical combination being aided by heat. Give some instances of its being opposed by heat. Define decomposition.

Give some instances of light affecting chemical combination. Give some instances of its affecting chemical decomposition.

Give any instances of chemical combinations and decompositions being influenced by electricity. What is the source of the electricity generally employed to produce chemical combinations or decompositions?

Define analysis. Synthesis.

Distinguish between proximate and ultimate analysis. Distinguish between qualitative and quantitative analysis.

CHAPTER II.

THEORY OF CHEMICAL COMBINATIONS.

DEFINITE AND MULTIPLE PROPORTIONS.
ATOMICITY AND QUANTIVALENCE.

13. The Indestructibility of Matter.—Matter is absolutely indestructible. By no possible means can a given quantity of matter be either increased or decreased. When chemical union occurs, the weight of the resulting body is always rigorously equal to the combined weight of its constituent elements, and is never either greater or less than such combined weight.

A piece of carbon burned in air finally disappears completely. It has not, however, been blotted out of existence, but has entered into combination with the oxygen of the air, and has formed an invisible gas. Moreover, the weight of the gas so formed is exactly equal to the sum of the weights of the combined carbon and oxygen.

14. Invariable Composition of Definite Substances. (*Dalton's Laws.*)—The same substance invariably possesses the same chemical composition, no matter where it may be found, or under what circumstances it may exist. Thus, an analysis of water shows that this substance consists of a definite union of two parts by weight of hydrogen, with sixteen parts by weight of oxygen. This analysis once made need never be made again. We may be sure that pure water, from any part of the world, has exactly the same composition.

15. Law of Definite Proportions.—Atomic Weights.—Since chemical combination results from the mutual attractions of the atoms, and the atoms are indivisible, they must unite with one another as wholes.

As we have already stated, all atoms of the same element have the same weight; the atoms of different elements have different weights. If, therefore, the atoms combine as wholes, there should exist definite proportions between the relative weights with which one elementary substance enters into combination with another. This we find by experiment to be the case.

If, therefore, we can determine the smallest proportions in which any two elements combine with each other, and can show that such combination must occur in the proportion of atom for atom, it follows that the proportions in which they combine will represent the relative weights of the combining atoms.

Thus, the smallest quantity of chlorine that can combine with 1 part by weight of hydrogen, weighs 35.5 times as much as the hydrogen. But 35.5 parts by weight of chlorine will also combine with exactly 39.1 parts by weight of potassium, and with no less. The 39.1 parts of potassium, therefore, bear the same relation to the 35.5 parts of chlorine that the 1 part of hydrogen does.

So also the smallest quantity of bromine that can combine with 1 part by weight of hydrogen, weighs 80 times as much. But 80 parts by weight of bromine will also combine with exactly 39.1 parts by weight of potassium, and with no less. The 39.1 parts by weight of potassium, therefore, bear the same relation to the 80 parts by weight of bromine, that the 1 part by weight of hydrogen does.

Again, the smallest quantity of chlorine that will combine with potassium is in the proportion of 35.5 parts by weight of chlorine to 39.1 parts by weight of potassium. And the smallest quantity of bromine that will combine with potassium, is in the proportion of 80 parts by weight of bromine, to 39.1 parts by weight of potassium.

The smallest quantities of hydrogen, chlorine, potassium, and bromine capable of entering into combination, are, therefore, as the numbers 1, 35.5, 39.1, and 80.

We are therefore justified in regarding these numbers as representing the relative weights of the atoms of hydrogen, chlorine, potassium, and bromine, respectively.

These numbers are called the *atomic weights*. It must be remembered, however, that they represent the relative weights of the atoms, the weight of the hydrogen atom being taken as unity; that is to say, although we do not know how much the atom of chlorine actually weighs, yet we believe that it weighs 35.5 times more than the atom of hydrogen.

The atomic weights of all the elementary substances have been determined with great care. There are, however, many difficulties in the way of determining these weights absolutely, and subsequent researches may require the values now given to be slightly altered. It is improbable, however, that such changes will necessitate any but trifling alterations.

16. Law of Multiple Proportions.—The above conclusions are, moreover, greatly strengthened by the following facts: Atomic combination does not only occur in the proportion of a single atom of one element to a single atom of another element. Sometimes a single atom of one element will combine with two, three, or more atoms of another element. Now, since the atoms are indivisible, this combination can never take place between any fractional part of an atom, but must always occur between one, two, three, four, or some whole number of atoms; consequently, if any one of the above-mentioned substances combines with any of the elements in higher proportions than its atomic weight just mentioned, such combination must occur in the proportion of two, three, four, or some other whole number of times such atomic weight. This we find to be the case.

Thus 71 parts by weight of chlorine combine with 118 parts of tin; that is (2 × 35.5, or 71), two atoms of chlorine combine with one atom of tin. But the same quantity of tin will combine with 142 parts of chlorine; that is, with 4 × 35.5, or four atoms of chlorine.

So also 12 parts by weight of carbon, or one atom, will combine either with 16 or with 32 parts of oxygen; that is, with one or with two atoms of oxygen.

The above laws of definite and multiple proportion will be better understood as additional examples present themselves in the further study of the science.

17. Atomic Symbols.—In order to secure ease in writing the names of the elementary substances, they are represented by certain symbols, which are generally taken as the initial letter in the name of the substance; thus, instead of writing the word hydrogen, we simply write the capital letter H; instead of writing nitrogen, we write N. So also S, C, and O represent sulphur, carbon, and oxygen, respectively.

Where several elements have the same initial letter, we use the first two letters—Se for selenium, Ca for calcium; or, if these have already been used, the first and some subsequent letter, as Cs for cæsium; or, we may use the initial letter, or the first two letters of the Latin name of the element, as K for potassium, taken from the Latin name *Kalium;* or Na for sodium, from the Latin name *Natrium;* or Fe for iron, from the Latin name *Ferrum;* or we may use the first letter and some subsequent letter of the Latin name, as Hg for mercury, from the Latin name *Hydrargyrum.*

The convenience of these symbols has been still further extended by causing them to stand for one atom of each of the elements they represent. Thus H not only signifies hydrogen, but also one atom of hydrogen. So also S, C, O, Se, and Cs, represent one atom each of sulphur, carbon, oxygen, selenium, and cæsium, respectively.

Where it is desired to represent more than one atom of a substance, numerals are affixed to the symbols; thus, H_4,C_2,O_3, which represent four atoms of hydrogen, two atoms of carbon, and three atoms of oxygen, respectively.

Combinations of the atoms are represented by writing the symbols next to one another; thus H_2O represents two atoms of hydrogen combined with one atom of oxygen; HBr represents one atom of hydrogen combined with one atom of bromine. So, also, H_2SO_4 represents the combination of two atoms of hydrogen, one of sulphur, and four of oxygen, united so as to form a single molecule.

Such expressions are called *chemical formulæ*, and represent the composition of the chemical molecule.

Where it is desired to represent a number of molecules, we prefix a larger figure; thus $2H_2O$ represents two molecules of H_2O. So, also, $4H_2SO_4$ represents four molecules of H_2SO_4. It will be seen that the formula $4H_2SO_4$ would be the same as $H_8S_4O_{16}$. It is not, however, so written since the molecule H_2SO_4 is a definite substance, and the formula simply indicates four of such molecules.

In order to indicate that a given substance has been produced by the combination of certain elements, they are written thus:

$$H_2 + O = H_2O.$$

Such expressions are called *chemical equations.* The number and kind of atoms in either of the members of such an equation, must always be rigorously equal to the number and kind of atoms in the other member.

The larger figures prefixed to a molecule only affect the atoms in such molecule. When it is desired that the prefix shall affect other molecules, the prefix is written outside a parenthesis, in which case it affects all the molecules within the parenthesis, thus:

$$4(H_2 + O) = 4H_2O.$$

A chemical equation generally indicates the effect produced by the addition of one substance to another with which it is capable of reacting chemically. Such equations are called *chemical* reactions.

The chemical reactions given in the text of this book are in general of great importance, and it is earnestly recommended that the student thoroughly familiarize himself with them. As an aid in this direction, it will be well to write the first member of the equation on a blackboard or on paper, and then work out the other member of the equation.

The following table gives, in alphabetical order, the names of the principal elementary substances, their symbols and atomic weights:

TABLE OF ELEMENTARY SUBSTANCES,

With their Symbols and Atomic Weights.

Names of the Elements.	Symbols.	Atomic Weights.	Names of the Elements.	Symbols.	Atomic Weights.
Aluminium	Al	27.5	Molybdenum	Mo	95.8
Antimony (*Stibium*) .	Sb	120	Nickel	Ni	59
Arsenic	As	75	Niobium (*Columbium*) .	Nb	94
Barium	Ba	137	Nitrogen	N	14
Bismuth	Bi	210	Osmium	Os	198.6
Boron	Bo	11	Oxygen	O	16
Bromine	Br	80	Palladium	Pd	106.2
Cadmium	Cd	112	Phosphorus	P	31
Cæsium	Cs	133	Platinum	Pt	197.5
Calcium	Ca	40	Potassium (*Kalium*) .	K	39.1
Carbon	C	12	Rhodium	Rh	104.1
Cerium	Ce	141.2	Rubidium	Rb	85.2
Chlorine	Cl	35.5	Ruthenium	Ru	103.5
Chromium	Cr	52.5	Selenium	Se	79.5
Cobalt	Co	59	Silicon	Si	28
Copper (*Cuprum*) . .	Cu	63.5	Silver (*Argentum*) . .	Ag	108
Didymium	Di	147	Sodium (*Natrium*) . .	Na	23
Erbium	Er	169	Strontium	Sr	87.5
Fluorine	Fl	19	Sulphur	S	32
Gallium	Ga	69.9	Tantalum	Ta	182
Glucinum (*Beryllium, Be*)	Gl	9.5	Tellurium	Te	128
Gold (*Aurum*) . . .	Au	197	Terbium	Tr	148.5
Hydrogen	H	1	Thallium	Tl	204
Indium	In	113.4	Thorium	Th	234
Iodine	I	127	Tin (*Stannum*) . . .	Sn	118
Iridium	Ir	192.7	Titanium	Ti	48
Iron (*Ferrum*) . . .	Fe	56	Tungsten (*Wolframium*)	W	183.5
Lanthanum	La	139	Uranium	Ur	240
Lead (*Plumbum*) . . .	Pb	207	Vanadium	V	51.37
Lithium	Li	7	Yttrium	Y	92.5
Magnesium	Mg	24	Zinc	Zn	65.2
Manganese	Mn	55	Zirconium	Zr	90
Mercury (*Hydrargyrum*)	Hg	200			

18. The Chemical Molecule.—It is, as we have seen, from the various combinations of the atoms of the elementary substances with themselves, or with one another, that *elementary* and *compound molecules* result.

All matter is composed of aggregations of these molecules united by their molecular attractions, that is, by cohesive or adhesive attractions—generally the former.

With these molecular attractions the chemist has but little to do. He is interested mainly in the composition and properties of the molecule; for, as we have seen, if the composition and chemical properties of any molecule be known, we know the composition and chemical properties of any other molecule of the same substance.

The physical properties, on the contrary, are influenced also by the relative positions of contiguous, or neighboring molecules.

Chemical analysis, strictly speaking, is therefore a separation of the molecule into its constituent atoms; while *synthesis* consists in the formation of the molecule by the combination of its constituent atoms.

19. Molecular Structure—Atomic Groupings in the Molecule.—Besides the qualitative and quantitative analysis of the molecule, it is found that the manner in which its constituent atoms are arranged, or grouped, exerts an influence on its properties. We must endeavor, therefore, to obtain some insight into the manner in which the atoms are arranged under the influence of their mutual attractions.

20. Variable Combining Capacity—Atomicity.—As we have already seen, chemical substances do not always combine atom for atom; sometimes one atom will combine with two, three, four, or even more atoms of another substance. In other words, the combining power of different atoms is unequal. An excellent example of this is furnished by hydrogen, which forms the following molecules, viz.:

HBr	H_2O	H_3N	H_4Si
Hydrobromic Acid.	Water.	Ammonia.	Hydrogen Silicide.
HCl	H_2S	H_3P	H_4C
Hydrochloric Acid.	Hydrogen Sulphide.	Hydrogen Phosphide.	Marsh Gas.

Here, as we see, hydrogen combines, in the first group, atom for atom; in the second group, two atoms of hydrogen are required to unite with one of oxygen, or sulphur, respectively; in the third group, three atoms of hydrogen are required for one atom of nitrogen, or phosphorus; in the fourth group, four atoms of hydrogen are required for one atom of silicon, or carbon.

The atoms of bromine and chlorine are, therefore, equivalent to one another in their combining power, since they each combine with one atom of hydrogen; so also the atom of oxygen is equivalent to that of sulphur, since each requires two atoms of hydrogen; nitrogen is equivalent to phosphorus, and silicon to carbon. The bromine, oxygen, nitrogen, and silicon; or the chlorine, sulphur, phosphorus, and carbon, are not equivalent to one another, for they each require a different number of atoms of hydrogen.

This relative equivalence of the atoms, or their atomic capacity, is known as their *atomicity.*

21. Quantivalence.—By the quantivalence of an atom we mean the expression of the value of its atomic capacity, or of its atomicities. Various terms are employed to express the quantivalence of an element. Thus, elements whose atomic capacity is

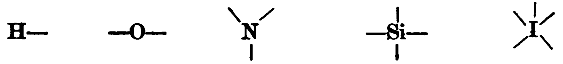
One,	are called	Monads	or	Univalent.
Two,	"	Dyads	"	Bivalent.
Three,	"	Triads	"	Trivalent.
Four,	"	Tetrads	"	Quadrivalent.
Five,	"	Pentads	"	Quinquivalent.
Six,	"	Hexads	"	Sexivalent.
Seven,	"	Heptads	"	Septivalent.

Those having a higher atomic capacity are called polyads or multivalent.

22. Representations of Quantivalence—Bonds.—As we have already said, the atoms do not touch when they are united to form the molecule. We may therefore regard a bivalent atom as possessing two points towards which it draws or attracts other atoms. These places where the atoms are drawn towards and fixed in position, as regards one another, may be regarded as *bonds*. Each atomicity, therefore, may be represented by a line or dash marking a bond; thus:

Monads.	Dyads.	Triads.	Tetrads.	Pentads.
H |	O ||	N |||	Si ||||	I |||||
Br |	S ||	P |||	C ||||	Bi |||||
Cl |	Cu ||	Bo |||	Al ||||	Ta |||||

or thus,



23. Empiric and Graphic Formulæ.—*Empiric Formulæ* are such as give merely the kind and number of the atoms in any molecule, as

HBr	H_2O	H_3N	H_4Si
Hydrobromic Acid.	Water.	Ammonia.	Hydrogen Silicide.

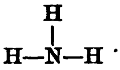
Graphic Formulæ are such as attempt to give the nature of the groupings of the atoms. Such formulæ are, of course, to a great extent ideal. They afford, however, a valuable aid in the substitution theory we shall shortly explain.

H—Br

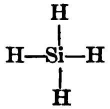
Hydrogen Bromide.

H—O—H

Water.



Ammonia.



Hydrogen Silicide.

24. Variable Atomicities of the Elements.—The elements very frequently possess more than one degree of atomicity; thus, sulphur, or iron, may act as a dyad, a tetrad, or a hexad; nitrogen, phosphorus, or arsenic, may act as a monad, a triad, or a pentad. These variations generally occur by twos; thus, a monad may become a triad, or a pentad, but not often a diad, or tetrad. So also a diad may become a tetrad, or a hexad, but rarely a triad, or a pentad.

Elements whose atomicities or quantivalence usually varies as the odd numbers, are sometimes called *perissads* (περισσως, uneven).

Elements whose atomicities or quantivalence usually varies as the even numbers, are sometimes called *artiads* (ἄρτιος, even).

Elements possessing varying degrees of atomicity generally exhibit marked differences in properties under different degrees of atomicity.

25. Molecular Condition of the Elements.—An element cannot exist in a free state with its bonds unneutralized or unsatisfied. If a bond were open it would immediately attract to it another element. Free hydrogen is molecular, thus, H—H. So also free iodine, I—I.

26. Tables of Quantivalence.—The following tables of the quantivalence of the elements will be convenient for reference.

Names of Elements usually Perissads.	Atomic Symbols.	Molecular Symbols.	Quantivalence.
Antimony (*Stibium*)	Sb	$Sb_2 \equiv Sb_2$?	III., V.
Arsenic	As	$As_2 \equiv As_2$	I., III., V.
Bismuth	Bi	$Bi_2 \equiv Bi_2$	III., V.
Boron	B	$B \equiv B$?	III.
Bromine	Br	Br—Br	I., III., V., VII.
Cæsium	Cs	Cs—Cs	I.
Chlorine	Cl	Cl—Cl	I., III., V., VII.
Fluorine	Fl	Fl—Fl	I.
Gold (*Aurum*)	Au	$Au \equiv Au$?	I., III.
Hydrogen	H	H—H	I.
Iodine	I	I—I	I., III., V., VII.
Lithium	Li	Li—Li	I.
Niobium (*Columbium*)	Nb	$Nb \equiv Nb$?	V.
Nitrogen	N	$N \equiv N$	I., III., V.
Potassium (*Kalium*)	K	K—K	I., III., V.
Phosphorus	P	$P_2 \equiv P_2$?	I., III., V.
Rubidium	Rb	Rb—Rb	I.
Silver (*Argentum*)	Ag	Ag—Ag?	I., III.
Sodium (*Natrium*)	Na	Na—Na	I., III.
Tantalum	Ta	$Ta \equiv Ta$?	V.
Thallium	Tl	Tl—Tl?	I., III.
Vanadium	Va	$Va \equiv Va$	V.

Names of Elements usually Artiads.	Atomic Symbols.	Molecular Symbols.	Quantivalence.
Aluminium	Al	Al?	IV.
Barium	Ba	Ba?	II.
Cadmium	Cd	Cd	II.
Calcium	Ca	Ca?	II., IV.
Carbon	C	C?	II., IV.
Cerium	Ce	Ce?	II., IV.
Chromium	Cr	Cr?	II., IV., VI.
Cobalt	Co	Co?	II., IV., VI.
Copper (*Cuprum*)	Cu	Cu?	II.
Didymium	D	D?	II.
Erbium	E	E?	II., IV.
Gallium	Ga	Ga?	IV., VI.
Glucinum	Gl	Gl?	II.
Indium	In	In?	II., IV., VI.
Iridium	Ir	Ir?	II., IV., VI.
Iron	Fe	Fe?	II., IV., VI.
Lanthanum	La	La?	II.
Lead (*Plumbum*)	Pb	Pb?	II., IV.
Magnesium	Mg	Mg?	II.
Manganese	Mn	Mn?	II., IV., VI.
Mercury (*Hydrargyrum*)	Hg	Hg	II.
Molybdenum	Mo	Mo?	II., IV., VI.
Nickel	Ni	Ni?	II., IV., VI.
Oxygen	O	O=O	II.
Osmium	Os	Os?	II., IV., VI.
Palladium	Pd	Pd?	II., IV.
Platinum	Pt	Pt?	II., IV.
Rhodium	Ro	Ro?	II., IV., VI.
Ruthenium	Ru	Ru?	II., IV., VI.
Selenium	Se	Se=Se	II., IV., VI.
Silicon	Si	Si≡Si?	IV.
Strontium	Sr	Sr?	II., IV.
Sulphur	S	S=S	II., IV., VI.
Tellurium	Te	Te=Te	II., IV., VI.
Terbium	Tr	Tr?	IV.
Thorium	Th	Th?	II.
Tin (*Stannum*)	Sn	Sn?	II., IV.
Titanium	Ti	Ti?	II., IV.
Tungsten (*Wolframium*)	W	W?	IV., VI.
Uranium	U	U=U	IV., VI.
Yttrium	Y	Y?	II.
Zinc	Zn	Zn?	II.
Zirconium	Zr	Zr?	IV.

SYLLABUS.

Matter is indestructible. By no possible means can a given quantity of matter be either increased or decreased.

When chemical union occurs, the weight of the compound body is always rigorously equal to the sum of the weights of its constituent elements.

Definite substances invariably possess the same chemical composition. If, for example, a specimen of pure water be analyzed, and its composition once determined, we may be assured that pure water from any part of the world has the same composition.

As the atoms are indivisible, they must unite with one another as wholes.

By the atomic weights of the elements we understand the relative weights of the atoms.

All atoms of the same element possess the same weight. The atoms of different elements possess different weights.

Some atoms, therefore, are much heavier than others; for example, the atom of bromine weighs eighty times more than the atom of hydrogen. The atom of mercury weighs two hundred times more than the atom of hydrogen.

As hydrogen is the lightest atom known, it is convenient to compare the weights of the other atoms with it.

The atoms do not always combine in the proportion of atom for atom. Sometimes an atom of one substance will combine with two, three, or more atoms of another substance.

As it is whole atoms only that combine when one substance combines with another in more than one proportion, the combining weights of the constituent atoms must always be a whole number of times their atomic weight. This is called the law of multiple proportions.

In order to briefly represent the different elementary substances, symbols are employed. These symbols generally consist of the first letter, or the first two letters of the ordinary name, or the Latin name of the substance, thus: O, Os, I, Fe, Hg, H.

Such symbols are also employed to represent one atom each of the substances for which they stand.

Where more than one atom is to be represented, numerals are affixed to the symbols, thus: H_2, S_3, Hg_3, I_5.

Combinations between the atoms are represented by writing the symbols in juxtaposition, thus: H_2O, HBr. Such expressions are chemical formulæ, and represent the composition of the chemical molecule.

Larger figures prefixed to the formula are employed to represent the number of the molecules; thus $2H_2O$ represents two molecules of H_2O.

Chemical analysis, strictly speaking, is the separation of the molecule into its constituent atoms. Synthesis is the formation of the molecule by the combination of its constituent atoms.

The chemical properties of the molecule are affected as well by the structure or grouping of its constituent atoms as by the nature of its atoms.

Most elementary substances are not limited to a single combining capacity.

The combining capacity of the atoms is called their atomicity.

By the quantivalence of an atom we mean the expression of the value of its atomic capacity, or of its atomicities.

Atoms whose quantivalence is one, are called monads; two, dyads; three, triads; four, tetrads; five, pentads; six, hexads; seven, heptads; more than seven, polyads.

An atom whose quantivalence is greater than one, must have more than one point or place from which it exerts an attraction for another atom. These places where the union occurs are called bonds. If the bonds have all attracted and fixed another atom or atoms, they are said to be closed, neutralized, or satisfied; if they have not so attracted other atoms, they are said to be open, or unsatisfied.

The atomicities or bonds may be represented by dashes, thus: H', O'', N''', Si'''', or Si^{iv}.

Empiric formulæ are such as give the kind and number of atoms in any molecule.

Graphic formulæ are such as attempt to give the nature of the groupings of the atoms.

All the elements may be arranged under two classes, viz.: the perissad, and the artiad.

Perissad elements are those whose atomicity or quantivalence usually varies as the odd numbers.

Artiad elements are those whose atomicity or quantivalence usually varies as the even numbers.

The bonds of an atom may be saturated or closed either by the bonds of another atom of the same kind of matter, or by those of an atom of a different kind of matter.

QUESTIONS FOR REVIEW.

What do you understand by the indestructibility of matter? Can the weight of a compound body ever differ from the sum of the weights of its constituents? Why?

Do all definite substances invariably possess the same chemical composition?

Why must all chemical combinations occur in definite or in multiple proportions?

Define atomic weights. Explain briefly how the atomic weights may be ascertained.

Have the atoms of the same substance invariably the same weight? How many times heavier is the atom of potassium than the atom of hydrogen?

Define atomic symbols. How much of each elementary substance does any of these symbols represent? By what means are several atoms represented?

Give the atomic symbols for the following elementary substances, viz., hydrogen, mercury, silver, sodium, sulphur, selenium, tungsten, and zinc.

By what means can the union or combination of the atoms be represented by symbols?

Give an example of the manner of representing a compound molecule by symbols. Define chemical formulæ. Chemical equation. Chemical reaction.

By what means are several molecules of a substance represented? Give an example.

Distinguish between the elementary and the compound molecule.

Define chemical analysis; synthesis.

Has the grouping of the atoms in a molecule any effect on its properties?

Do all chemical substances combine atom for atom? Define atomicity; quantivalence.

What name is given to elements whose atomic capacity is one? To those whose atomic capacity is two? three? four? five? six? more than six?

Explain in full what is meant by the bonds of an element. How many bonds has an univalent element? A quadrivalent element? A septivalent element?

Distinguish between empiric and graphic formulæ.

Do most of the elements possess a single quantivalence only, or have they more than one quantivalence?

Distinguish between perissad and artiad elements.

Why cannot an element exist in a free state if it has any of its bonds unsatisfied?

To which of the above groups do the following elements belong; to the perissads, or to the artiads, viz.: hydrogen, chlorine, silver, mercury, iron, fluorine, sulphur, uranium, and copper?

CHAPTER III.

THEORY OF SUBSTITUTION.

CHEMICAL NOMENCLATURE.

27. Completeness of the Chemical Molecule.—The chemical molecule is always complete in itself; for, like the atom, it could not exist in a free state if any of its bonds were unsatisfied.

A molecule, therefore, forms a complete unit of chemical existence and possesses all the chemical properties of the substance.

It was formerly believed that the atoms combined together in pairs, and formed compounds which again combined in pairs, these again sometimes combining in higher pairs. When decomposition occurred, it was observed always to first affect the highest pair, then the next, and finally the lowest. The decomposition between the atoms was called single decomposition, that between the first two pairs, double decomposition. But it is now well understood that the chemical molecule forms a compound complete in itself, since all of its bonds are satisfied.

28. Theory of Substitution.—Since the molecule has all its bonds satisfied, it cannot enter into further combinations, unless some of its bonds become free. This may occur by one or more of its constituent atoms being replaced in the molecule by some other atoms, or by an unsatisfied molecule. Such a process is called *replacement*, or *substitution*. By it nearly all the constituent atoms of a molecule may be replaced by atoms of elements entirely different from those it originally contained. This is known as the theory of substitution, and forms one of the most important principles in theoretical chemistry. To thoroughly appreciate its importance, it is necessary to carefully study the structure of the molecule as affected by the quantivalence of its constituent elements.

29. Influence of the Bonds in Substitution.—The theory of replacement is exceedingly simple. Let us suppose that one of the bonds of a satisfied molecule is suddenly opened by one of its constituent monadic elements leaving it. This bond can now at once be closed by any other unsatisfied atom or molecule possessing one free bond.

But for any of the constituent parts of a satisfied molecule to leave it, a decomposition must take place. In the case of most substitutions, this decomposition is caused by the greater attraction or superior affinity of some substance outside the molecule.

Thus if a piece of potassium be thrown on water it runs rapidly over the surface and burns with a violet flame. It decomposes the water, setting hydrogen free, and entering into combination with the remaining unsatisfied molecule.

30. Radicals, Simple and Compound.—Any unsatisfied or unsaturated molecule that has one or more free bonds is called a radical. The name has also been applied to an elementary atom whose bonds are free. There are, therefore, two kinds of radicals, viz., *simple* and *compound.*

The radical may be regarded as the basis to which the replacing elements are added, or as the nucleus around which they are clustered.

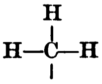
The simple radicals embrace all the elementary substances. They are naturally arranged or classified into two great groups, viz., the *non-metals*, and the *metals;* the former are electro-positive in character, the latter electro-negative.

An electro-positive substance is one that would be attracted to the negative terminal of a voltaic battery; an electro-negative substance is one that would be attracted to the positive terminal.

As any unsatisfied molecule may act as a radical, the number of compound radicals must, therefore, be very great. We recognize as compound radicals, however, mainly those capable of acting as nuclei, and producing a definite molecular structure.

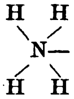
31. The Quantivalence of the Radicals.—The quantivalence of a radical depends on the number of its unsatisfied bonds. Although compound radicals cannot be isolated, since they would then have some of their bonds unsaturated, yet, like the simple radicals, they may unite with one another in pairs, when, of course, they can exist free.

The following examples of compound radicals will serve to render the foregoing principles more readily understood, viz.:



$$\begin{array}{c} H \\ | \\ H-C-H \\ | \end{array}$$

Methyl.



Ammonium.

are *compound univalent radicals.*

32. The Complexity of the Molecule Dependent on the Quantivalence of its Constituents.—An univalent radical produces the simplest molecular structure, for example,

$$H-Cl$$

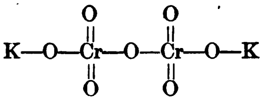
Hydrochloric Acid.

A bivalent radical introduces greater complexity, thus:

$$H-O-H \quad \text{or} \quad H-O-O-H$$

Water. Hydrogen Dioxide.

The complexity rapidly increases, until with atoms of higher quantivalence we obtain great complexity, as the following shows:



$$\begin{array}{ccccccccc} & & O & & & & O & & \\ & & \| & & & & \| & & \\ K & - O - & Cr & - & O & - & Cr & - O - & K \\ & & \| & & & & \| & & \\ & & O & & & & O & & \end{array}$$

Potassium Bichromate.

33. Acids and Bases.—Excellent illustrations of the principles of substitution are afforded by the formation of an exceedingly large class of chemical molecules called acids and bases. These bodies are substitution compounds, of a compound radical called *hydroxyl,* which results from the removal of one of the hydrogen atoms in the molecule of water. Thus:

$\mathrm{H-O-H}$ = Water.
$\mathrm{H-O-Cl}$ = Hypochlorous Acid.
$\mathrm{H-O-(PO_2)}$ = Meta-phosphoric Acid.
$\mathrm{H-O-(NO_2)}$ = Nitric Acid.

So also

$\mathrm{H-O-H}$ = Water.
$\mathrm{Na-O-H}$ = Caustic Soda.
$\mathrm{K-O-H}$ = Caustic Potash.

The substances in the first group are all acids. Acids have a sour taste; are corrosive; turn vegetable blues red; have a powerful affinity for bases, and are electro-negative. When formed as substitution compounds, the element or radical that combines with the hydroxyl is always electro-negative. Their general formula is $\overset{-}{\mathrm{R}}\mathrm{-O-H}$.

Acids are substitution compounds formed by the combination of an electro-negative substance with hydroxyl.

The substances in the second group are bases. Bases have an acrid taste; restore the blue color to reddened vegetable blues; have a powerful affinity for acids, and are electro-positive. Their general formula is $\overset{+}{\mathrm{R}}\mathrm{-O-H}$.

Bases are substitution compounds formed by the combination of an electro-positive substance with hydroxyl.

34. Salts.—When acids and bases are brought together, an energetic reaction ensues, and a body called a salt is produced. The same molecular structure is preserved in the molecules of the salt as existed in either the acid or the base. Thus:

$$\underset{\text{Acid.}}{\overset{-}{\mathrm{R}}\mathrm{-O-H}} + \underset{\text{Base.}}{\overset{+}{\mathrm{R}}\mathrm{-O-H}} = \underset{\text{Salt.}}{\overset{+}{\mathrm{R}}\mathrm{-O-}\overset{-}{\mathrm{R}}} + \underset{\text{Water.}}{\mathrm{H-O-H}}$$

Salts are substitution compounds in which an electro-positive radical or element is united to an electro-negative radical or element by means of oxygen.

Thus:

$$\underset{\text{Nitric Acid.}}{\mathrm{H-O-(NO_2)}} + \underset{\text{Potassium Hydrate.}}{\mathrm{K-O-H}} = \underset{\text{Potassium Nitrate.}}{\mathrm{K-O-(NO_2)}} + \underset{\text{Water.}}{\mathrm{H-O-H}}$$

There are some salts that contain no oxygen whatever, such for example as Na—Cl. These have been called *haloid salts*, (ἁλός, ἔιδος, having the form of a salt, or resembling a salt). The compounds of hydrogen with chlorine, iodine and fluorine, though often called acids, contain no oxygen, and do not, therefore, belong to the general type of acids above described. They are sometimes called *hydracids*.

35. Chemical Nomenclature.—In order to prevent confusion in the names of the almost innumerable chemical substances that exist, their *nomenclature*, as far as possible, has been so devised that the name of a substance shall indicate its chemical composition.

While chemistry was confined to the alchemists, many fanciful names were introduced, some of which are still retained in science. So, also, the names given to substances when the old ideas of combination by pairs were held, have also influenced the nomenclature now employed.

The following principles will serve to briefly explain the present nomenclature.

36. Terminations of the Metals and Radicals.—All the metals, except those discovered very early in the history of the science, end in *um;* as potassium, sodium, calcium, barium, and strontium.

Those already named before this termination was adopted, as iron, lead, tin, gold, silver, etc., have the *um* in their Latin names, as ferrum, plumbum, stannum, aurum, argentum, etc.

The inorganic compound radicals generally terminate in *yl*, as hydroxyl, carbonyl, etc.

37. Names and Terminations of the Binary Compounds.—The names of binary compounds, that is, those formed by the union of two elements, end in *ide*. In these compounds the positive element is always both written first, and named first.

The termination of the positive element remains unchanged, except in cases where it combines with the negative element in more than one proportion, in which case the termination *ous* is affixed to the compound containing the greatest amount of the positive element, and *ic* to the one containing the least of this element.

A few illustrations will serve to show the use of such terminations:

$NaCl$ = Sodium chlor*ide*.

Here the name of the positive element, sodium, remains unchanged, while the name of the negative element of the binary compound ends in *ide;* so also

ZnS = Zinc Sulph*ide*.
ZnO = Zinc ox*ide*.
$AgCl$ = Silver chlor*ide*.
KCl = Potassium chlor*ide*.
HCl = Hydrogen chlor*ide*.
HBr = " brom*ide*.
HI = " iod*ide*.
HFl = " fluor*ide*.

SO_2 = Sulphur*ous* ox*ide*.
SO_3 = Sulphur*ic* ox*ide*.
FeO = Ferr*ous* ox*ide*.
Fe_2O_3 = Ferr*ic* ox*ide*.

Here the termination *ous* is given to the SO_2, which contains the most of S, the positive element, and *ic* to the SO_3, which contains the least of the positive element. So also with the ferrous, and the ferric oxides.

Varying proportions of the elements are indicated by the prefixes *mon, di, tri, tetra,* and *pent,* signifying respectively one, two, three, four, and five. Thus,

N_2O = Nitrogen *mon*oxide.
N_2O_2 = " *di*oxide.
N_2O_3 = " *tri*oxide.
N_2O_4 = " *tetr*oxide.
N_2O_5 = " *pent*oxide.

38. Nomenclature of Acids, Bases, and Salts.—The terminations *ic* and *ous* are given to acids; *ous* being applied to the one that contains the larger quantity of the positive element, or what is the same thing, the smaller quantity of oxygen, the negative element. Thus,

H_2SO_3 = Sulphur*ous* acid.
H_2SO_4 = Sulphur*ic* acid.

In naming a salt, the positive element is named first. The terminations *ic* and *ous* are given to it as in the case of the binary compounds just named. Sometimes the positive element keeps its termination *um*.

In forming a salt, the termination *ic* of the acid changes into *ate*, and the *ous* into *ite*. Thus,

KNO_3 = Potassium nitr*ate*.
K_2SO_4 = " sulph*ate*.
K_2CO_3 = " carbon*ate*.

So also

$NaNO_3$ = Sodium nitr*ate*.
Na_2CO_3 = " carbon*ate*.

But

KNO_2 = Potassium nitr*ite*.
Na_2SO_3 = Sodium sulph*ite*.

* * *

SYLLABUS.

The unit of chemical existence is the chemical molecule. It is complete in itself, and possesses all the chemical properties of the substance.

The complete chemical molecule has all its bonds closed or saturated. It cannot, therefore, enter into further combination unless some of its constituent atoms are replaced by others.

The replacing substances may be either free atoms, or unsatisfied molecules.

The formation of a new molecule by the replacing of some of its atoms by free atoms or unsatisfied molecules occurs by displacement, or, as it is frequently called, by substitution.

The properties of the chemical molecule are influenced by its structure; that is, by the grouping or arrangement of its constituent elements, as well as by the kind or nature of its constituent elements.

The general structure of the molecule may be preserved, even though all its original atoms are replaced.

Molecules with similar groupings or structure may have similar chemical properties, though their atomic composition is different.

When an unsaturated molecule, or free atom is brought into contact with a saturated molecule, it may drive out some of the more weakly-linked atoms, and enter into combination with the rest of the molecule.

An atom or molecule, whose bonds are not all closed or saturated, is called a radical. Radicals may, therefore, be simple or compound.

All radicals may be divided into two classes, viz.: electro-positive, or such as are attracted towards the negative terminal of a voltaic battery, and electro-negative, or such as are attracted towards the positive terminal.

The simple radicals may be divided into two classes, viz., the metals and the non-metals. The former are electro-positive; the latter, electro-negative.

Radicals possess a quantivalence that varies with the number of their open or unsaturated bonds.

The complexity of structure of the molecule is dependent on the quantivalence of its constituent atoms.

Univalent radicals produce the least complexity of structure in the molecule. Bivalent radicals produce a more complex molecular structure. The multivalent radicals generally produce very complex molecules.

Acids are bodies that have a sour taste; turn vegetable blues red; have a powerful affinity for bases, and are electro-negative.

Acids are substitution compounds formed by the combination of an electro-negative substance with hydroxyl.

Bases are bodies that have a bitter taste; restore the color to reddened vegetable blues; have a powerful affinity for acids, and are electro-positive.

Bases are substitution compounds formed by the combination of an electro-positive substance with hydroxyl.

When acids and bases are brought together an energetic reaction ensues, and bodies called salts are formed.

A salt consists of an electro-positive substance linked to an electro-negative substance by means of oxygen.

Acids, bases, and salts have the same molecular structure; viz., that of water.

Haloid salts are those which contain no oxygen whatever. Haloid means having the form of, or resembling, salt.

The compounds of chlorine, iodine, bromine, and fluorine with hydrogen, form a class of bodies possessing acid properties. They are sometimes called the hydracids.

In most cases the name of a chemical substance is so arranged that it indicates the chemical composition.

Most of the metals end in *um*. Where the metal has some other termination, its Latin name is made to end in *um*.

Most of the compound radicals end in *yl*.

Binary compounds end in *ide*.

The positive element is always both written first and named first.

The positive element has its termination unchanged. Where, however, the positive element combines with the negative element in more than one proportion, the termination *ous* is used for the compound containing the greatest amount of the positive element, and *ic* for the one containing the least amount of this element.

The combination of one element with another in the proportion of one, two, three, four, and five, are indicated by the prefixes *mon*, *di*, *tri*, *tetra*, and *pent*, respectively.

Acids end in *ic* and *ous*. *Ous* indicates a larger proportion of the positive element, or, what is the same thing, a smaller proportion of the negative element.

When an acid and a base react so as to form a salt, the *ic* of the acid is changed into *ate*, and the *ous* into *ite;* thus sulphur*ic* acid forms sulph*ates;* sulphur*ous* acid, sulph*ites*.

* * *

QUESTIONS FOR REVIEW.

Why must the chemical molecule be complete in itself?

Describe the old idea of combination by pairs. In what respect does it differ from the present unitary theory?

What must happen to the chemical molecule before it can enter into further combinations?

Describe the theory of substitution. How does this principle enable the molecule to maintain its characteristic structure?

Explain the nature of the effect that superior affinity produces when two substances are brought into contact.

Upon what does the number of elements that can enter a substance by displacement depend?

Define a radical. Into what two classes may radicals be divided?

Into what two classes may all the elementary radicals be divided? Which of these are electro-positive? Which are electro-negative?

Upon what does the quantivalence of a radical depend?

Can compound radicals be completely isolated? Why?

Why must the complexity of the molecular structure depend upon the quantivalence of its constituents?

Which would produce the more complex molecule, an univalent or a bivalent radical? A bivalent or a multivalent radical?

By what properties are acids characterized? How are they formed? Upon what molecular type are they constructed?

By what properties are bases characterized? How are they formed? Upon what molecular type are they constructed?

What are salts? How are they formed? Upon what molecular type are they constructed?

Show by means of examples that acids are substitution compounds in which an electro-negative element replaces one of the hydrogen atoms in the molecule of water.

Show by means of examples that bases are substitution compounds in which an electro-positive element replaces one of the hydrogen atoms in the molecule of water.

Show by means of examples that salts are bodies in which an electro-positive element is linked to an electro-negative element by means of oxygen.

Define haloid salts; hydracids.

Show by means of an example that the nomenclature of any chemical substance is so constructed as to indicate its composition.

In what two letters do the names of most of the metals terminate? What are the terminal letters of most of the compound radicals?

In what three letters do all binary compounds terminate?

Which of the constituents of a binary compound is written first? Which is named first? What terminations are given to the electro-positive element? Explain when each of these is used.

Give the correct nomenclature for each of the following chemical molecules, and give your reasons in full for the names you use, viz.: $NaCl$, ZnO, ZnS, KCl, HCl, HBr, HFl, and SO_2, SO_3, FeO, and Fe_2O_3.

Explain the meaning of the prefixes, mon, di, tri, tetra, and pent.

Give the correct names for the following chemical molecules, viz.: N_2O, N_2O_2, N_2O_3, N_2O_4, and N_2O_5.

Which contains the more oxygen, an acid terminating in *ic*, or in *ous*? Illustrate by an example.

Into what does the *ic* of an acid change when it forms a salt? Into what does the *ous* change?

Give the correct nomenclature for each of the following chemical molecules, and explain how you form the words you use, viz.: KNO_3, K_2SO_4, K_2CO_3, $NaNO_3$, Na_2CO_3, KNO_2, and Na_2SO_3.

CHAPTER IV.

COMBINATION BY VOLUME.

GAY LUSSAC'S LAWS.—MOLECULAR VOLUME.

39. Combination by Volume.—We have already seen that certain invariable relations always exist between the combining weights of elementary substances, and that this ratio is invariably either that of their atomic weights, or of two, three, four, or more times their atomic weights.

This we have been able to readily understand, since the combinations take place atom for atom, and the atoms being indivisible, cannot unite, except as one, two, three, or more atoms; *that is, atoms combine as wholes and not as parts.*

Now it is also a fact that the gaseous elements that are capable of combining with one another, have definite relations between the volumes that so combine. A given volume of one gas will combine with an equal volume of another gas, or with two, three, or four times this volume, but it will not combine with one and a half, or one and a third, or any fractional part of this volume. *That is, gases combine by equal volumes, or by whole multiples of equal volumes.*

In making a comparison between the volumes of gases that enter in combination, we must measure the gases at the same temperature and pressure, because otherwise a given volume of a gas would be a variable quantity. For, since gases expand by heat, and are condensed by pressure, a high temperature and a low pressure would greatly increase the volume of the gas, while a low temperature and high pressure would greatly decrease it.

40. Relation between the Weights of Equal Volumes of Gases and their Atomic Weights.—A very significant fact has been discovered as to the relation existing between the weights of equal volumes of gases, measured at the same temperature and pressure, and their atomic weights, viz., *the weights of equal volumes of different gases are in the ratio of their atomic weights;* and, if these weights be compared with the weight of a unit volume of hydrogen, they will be the same as the atomic weights. Thus, if

The unit volume, say one cubic inch, of	hydrogen,	weighs	1, then
" " " " "	oxygen,	"	16,
" " " " "	nitrogen,	"	14,
" " " " "	chlorine,	"	35.5,
" " " " "	iodine,	"	127;

in which case, as will be observed, the weights of the equal volumes are identical with the atomic weights of the substances.

41. Conclusions from the Preceding. Theorem of Avogadro.—The conclusion to be deduced from the above is inevitable: equal volumes of all elementary gases must contain the same number of atoms, or rather, since the atoms cannot exist in a free state, equal volumes of all gases, measured at the same temperature and pressure, must contain the same number of molecules.

The above principle is known as the theorem of Avogadro, from the name of its discoverer. It is applicable to all gases, whether elementary or compound, but in the case of compound gases, is true of the molecules only, as we shall hereafter see.

42. Circumstances Establishing the Theorem of Avogadro.—Although we cannot establish the principle of Avogadro by direct proof, yet there are a number of circumstances that tend to show its correctness almost beyond doubt.

1st. *The expansion and contraction of gaseous bodies.* Equal changes in temperature do not produce equal changes in the bulk or volume of different solids or liquids; for, some expand or contract much more than others. This is not the case, however, with gaseous bodies or with vapors. Equal volumes of gases or vapors, measured at the same temperature and pressure, undergo equal changes in volume, if subjected to the same increments or decrements of heat.

The assumption that the equal volumes of gases or vapors contain the same number of molecules renders the above fact easy of explanation.

2d. *The specific heat of elementary and compound substances.*

The specific heat of a body is the amount of heat required to raise the temperature of a given weight of the body one degree, as compared with the amount of heat necessary to raise the temperature of an equal weight of water one degree.

Equal volumes of all gases, measured at the same temperature and pressure, have the same specific heat. Moreover, the product of the specific heat of equal weights of solid and liquid elements, by the atomic weights, is nearly constant. These circumstances are explained on the assumption that equal volumes of all gases contain the same number of molecules.

43. Equal Numbers of all Gaseous Molecules Occupy Equal Volumes.—If the relative proportions by weight, according to which elementary bodies combine, represent the relative weights of the combining atoms, the relative proportions by volume, according to which gases combine, must represent the relative volumes occupied by the combining atoms.

As we have seen, these proportions by volume are simple and definite; if, therefore, under equal conditions of temperature and pressure, equal volumes of gases contain the same number of molecules, we may infer that all gaseous molecules occupy the same bulk.

Strictly speaking, the distance between the centres of contiguous molecules is the same in all gases.

This theoretical deduction is greatly strengthened by the fact that, when gaseous combination occurs by volume, the volumes being measured by the most simple ratio according to which the gases combine;

The volume of the resulting gas is always equal to two unit volumes, no matter how many volumes of the gases have entered into combination.

That is, when two equal volumes of elementary gases enter into combination, no shrinkage occurs, the resulting volume being equal to the sum of the two volumes; but where the combining volumes are not equal, a shrinkage always occurs, until the compound occupies exactly two volumes. Thus,

$$\boxed{\mathrm{H}} + \boxed{\mathrm{Cl}} = \boxed{\mathrm{HCl}}$$

One volume Hydrogen + One volume Chlorine = Two volumes Hydrogen Chloride.

$$\boxed{\mathrm{H}}\ \boxed{\mathrm{H}} + \boxed{\mathrm{O}} = \boxed{\mathrm{H_2O}}$$

Two volumes Hydrogen + One volume Oxygen = Two volumes Water Vapor.

$$\boxed{\mathrm{H}}\ \boxed{\mathrm{H}}\ \boxed{\mathrm{H}} + \boxed{\mathrm{N}} = \boxed{\mathrm{NH_3}}$$

Three volumes Hydrogen + One volume Nitrogen = Two volumes Ammonia.

$$\boxed{\mathrm{H}}\ \boxed{\mathrm{H}}\ \boxed{\mathrm{H}}\ \boxed{\mathrm{H}} + \boxed{\mathrm{C}} = \boxed{\mathrm{CH_4}}$$

Four volumes Hydrogen + One volume Carbon = Two volumes Marsh Gas.

Here we see that the molecules of hydrogen chloride, water vapor, ammonia, and marsh gas, all occupy the same volume.

44. Actual Size of the Molecule.—Although the molecules are exceedingly small, yet, as we have seen, they have a definite size. By means of various refined researches in physics, we have been enabled to form some idea of the magnitude of these almost infinitesimal particles. In one cubic inch of air, at 32° F., and 30 inches barometric pressure, there are one hundred thousand million million million, or 10^{23}, an almost inconceivable number.

45. Molecular Weight.—The relative molecular weight of any two gases or vapors is readily obtained by measuring equal volumes of these gases, or vapors, at the same temperature and pressure, and weighing them. When, since each contains the same number of molecules, the weights must give the relative molecular weights of the two gases. If a cubic inch of nitrogen weighs fourteen times as much as a cubic inch of hydrogen, then, as each contains the same number of molecules, the hydrogen molecule must be fourteen times lighter than the nitrogen molecule.

Since the specific gravity of a gas represents the number of times that a given volume is heavier or lighter than an equal volume of some other gas taken as a standard of comparison, if the specific gravity of the gas be compared with hydrogen, it is only necessary to multiply this specific gravity by two, in order to obtain the molecular weight of the gas. We must multiply by two, because the single volume of hydrogen is the unit of atomic weight, and the molecule occupying two volumes will weigh two.

If the specific gravity of the gas or vapor be given as compared with air, multiply the density by 14.44, and the product will give the specific gravity as compared with hydrogen, because air is 14.44 times as heavy as hydrogen.

SYLLABUS.

Bodies always combine in definite or multiple proportions, because the atoms combine as wholes, and not as parts.

Gaseous elements combine with one another in certain definite proportions by volume. They may combine in equal volumes; or one volume of a certain gas may combine with two, three, or more volumes of another gas; but they always combine in the proportion of whole volumes, and never in that of parts of a volume.

The weights of equal volumes of gases, measured at the same temperature and pressure, are in the ratio of their atomic weights. We therefore conclude that equal volumes of elementary gases contain the same number of atoms, or rather, since the atoms cannot exist separately, the same number of molecules.

The theorem of Avogadro is, "Equal volumes of all gases (whether elementary or compound), measured at the same temperature and pressure, contain the same number of molecules."

The fact that equal volumes of all gases expand or contract equally by equal increments or decrements of heat, seems to show that equal volumes contain the same number of molecules.

The facts that equal volumes of all gases, measured at the same temperature and pressure, have the same specific heat, and that for all elements the product of the specific heat and the atomic weight is nearly constant, show that equal volumes of all gases must contain the same number of molecules.

All gaseous molecules occupy the same space, or have the same volume or size.

When gaseous bodies combine by volume, the resulting gaseous substance invariably occupies a volume equal to two unit volumes; therefore, when a single volume of one gas combines with a single volume of another gas, no shrinkage occurs.

The molecules, though almost inconceivably small, have a definite size, which can be approximately measured.

To determine the weight of a gaseous molecule, it is only necessary to determine the weight of a unit volume of the gas, and compare it with the weight of a unit volume of hydrogen.

If the specific gravity of a gas be known as compared with hydrogen, its molecular weight may be obtained by multiplying the density by two.

The specific gravity of a gas compared with air, multiplied by 14.44, will give its specific gravity as compared with hydrogen.

QUESTIONS FOR REVIEW.

Why do bodies always combine with one another in definite or multiple proportions?

In what respect are the proportions in which gases combine by volume also definite?

Why must the volumes of gases be measured at the same temperature and pressure, when compared with one another?

Explain the relation existing between the weights of equal volumes of gases and their atomic weights.

State the theorem of Avogadro. What reasons can you deduce for its probable correctness?

Do equal volumes of all gases, whether simple or compound, contain the same number of atoms, or the same number of molecules?

What probable explanation can you give of the fact that all gases have the same degree of expansion or contraction when exposed to the same changes of temperature?

What is meant by the specific heat of a substance?

Under what circumstances have all gases the same specific heat?

What fact has been ascertained respecting the product of the specific heat and the atomic weight of solid and liquid elements?

Prove that all gaseous molecules must occupy the same volume or have the same size.

Under what circumstances may gases combine without undergoing a contraction in volume? Under what circumstances will contraction ensue? To what is the volume of the resulting gas invariably equal?

What facts have been discovered concerning the actual size of the molecule?

Define molecular weight. How may the molecular weight of any gaseous substance be readily ascertained?

What relation exists between the molecular weight of a compound gaseous substance and its specific gravity as compared with hydrogen?

What would be the simplest way of showing that the nitrogen molecule is fourteen times heavier than the hydrogen molecule?

If the specific gravity of a gaseous substance be given as compared with air, how may its specific gravity as compared with hydrogen be readily ascertained?

CHAPTER V.

CRYSTALLOGRAPHY.

46. Crystalline and Amorphous Conditions of Solids.—All solid substances are either *crystalline* or *amorphous.*

A crystalline solid is one bounded by symmetrically arranged surfaces. Nearly all solid chemical substances have definite forms, which characterize them as fully as do the forms peculiar to plants and animals.

An amorphous solid is one in which no traces of crystalline form are discernible.

The crystalline form results from the action of the force of cohesion, which arranges the molecules in the characteristic shapes assumed by the crystal.

47. Conditions Favorable to the Crystallization of Solids.—In order that the force of cohesion may readily group the molecules of a solid in a regular crystalline shape, it is necessary that the molecules have sufficient freedom of motion at the moment they are assuming the solid condition. This freedom of motion is obtained as follows, viz.:

1st. *By dissolving the solid,* and then allowing the solution to slowly evaporate. The solution of the solid is sometimes aided by heat.

2d. *By melting or fusing* the substance by heat, and then allowing it to slowly cool.

3d. *By sublimation;* that is, by vaporizing the substance, and allowing its vapor to slowly condense in suitably arranged vessels.

4th. *By chemical decomposition.* Many solutions, when mixed together, decompose one another and form a solid precipitate, so called because it generally falls to the bottom of the liquid, though sometimes it rises to the surface. These precipitates are generally crystalline.

5th. *By electrical decomposition.* When an electrical current is passed through a metallic solution, the metal is often separated in a crystalline condition.

48. Definitions.—*The face of a crystal* is the plane surface that bounds it, as *a b c d*, Fig. 1.

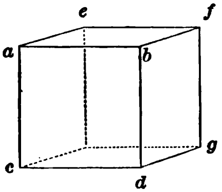


Fig. 1.—A Crystal.

The edge of a crystal is the line formed by the intersection of two contiguous faces, as *b d*, which is formed by the intersection of the face *a b c d* with the face *b d f g*.

The *solid angles* are situated at the point where three or more intersecting faces meet.

The faces of a crystal are *similar* when they have the same form in a similar position; and *dissimilar*, when their form is different in similar positions. Crystals bounded by similar faces have *simple forms;* those bounded by dissimilar faces have *complex forms.*

49. Modifications of Crystals.—The crystalline forms in which solids generally occur are subject to many modifications; for example, the cube, Fig. 2, sometimes occurs with

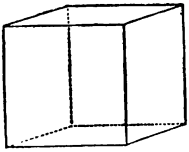


Fig. 2.—Cube.

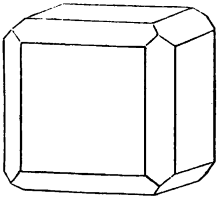


Fig. 3.—Cube with edges cut off by single plane.

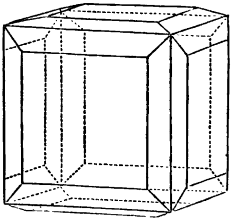


Fig. 4.—Cube with edges cut off by two equally inclined planes.

its edges or angles cut off or *replaced* by one or more planes. Thus, in Fig. 3, the *cube* is shown with its edges cut off by a single plane; in Fig. 4, it is shown with its edges cut off by two planes equally inclined to adjacent faces.

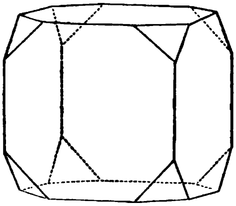


Fig. 5.—Cube with solid angles cut off by single plane.

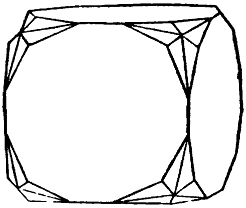


Fig. 6.—Cubes with solid angles cut off by equally inclined planes.

Or the solid angles may be thus cut off, as shown in Fig. 5, by a single plane, or as in Fig. 6, by more than one plane.

Sometimes, instead of all the edges or angles being modified, only every other edge or angle is thus affected, as shown in Fig. 7.

When all the edges or angles of a crystal are cut off, the modification is said to be *holohedral* (all the faces). When only the alternate edges or angles are cut off, the modification is said to be *hemihedral* (half the faces).

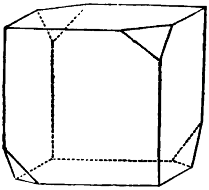


Fig. 7.—Cube with alternate angles cut off.

50. Systems of Crystallography.—The preceding modifications produce a great variety in the forms in which crystalline substances occur. Notwithstanding their diversity they may, however, be arranged under the six following characteristic types or systems, viz.:

1st. *The Monometric system,* sometimes called the isometric or cubic system.

2d. *The Dimetric system,* sometimes called the quadratic or square prismatic system.

3d. *The Trimetric system*, sometimes called the rhombic system.

4th. *The Monoclinic system*, sometimes called the oblique rhombic system.

5th. *The Triclinic system*, sometimes called the oblique rhomboidal system.

6th. *The Hexagonal system*, sometimes called the rhombohedral system.

These systems are based on the number, length, and inclination of *the axes of the crystals;* that is, the imaginary lines passing through the centre of the crystal and terminating in the centres of the opposite faces, edges, or angles.

51. The Monometric System (from *monos*, one, and *metron*, measure) has three axes of equal length, at right angles to one another, as shown in the cube in Fig. 8, where the axes *a a*, *b b*, and *c c*, are all of the same length, and are at right angles to one another.

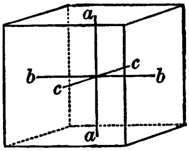


Fig. 8.—A Crystal of the Monometric System.

The *simple forms* belonging to this system are shown in Figs. 9, 10, and 11.

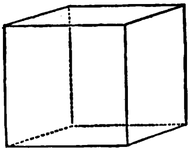


Fig. 9.—The Cube.

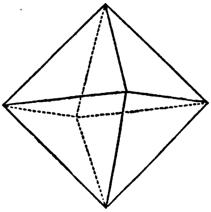


Fig. 10.—The Regular Octahedron.

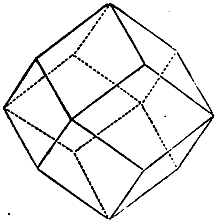


Fig. 11.—The Rhombic Dodecahedron.

They are *the cube*, the *regular octahedron*, an eight-faced figure, and *the rhombic dodecahedron*, a figure with twelve rhombic faces. The last two forms are modifications of the cube.

Some of the holohedral modifications, as actually found in chemical substances, are shown in Figs. 12, 13, and 14.

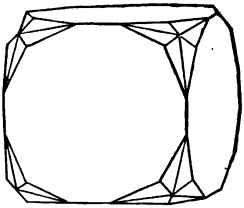


Fig. 12.
Fluor-Spar.

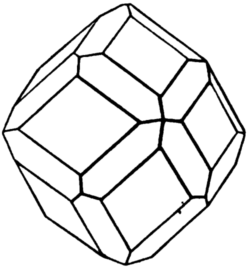


Fig. 13.
Garnet.

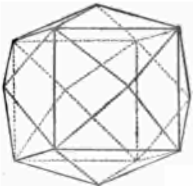


Fig. 14.
Crystal of Copper.

Some of the hemihedral modifications, as actually found in chemical substances, are shown in Figs. 15, 16, and 17.

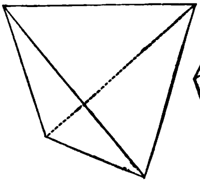


Fig. 15.—A Tetrahedron of Gray Copper.

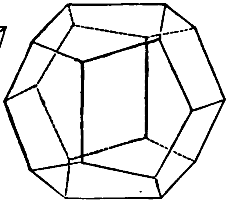


Fig. 16.
Iron Pyrites.

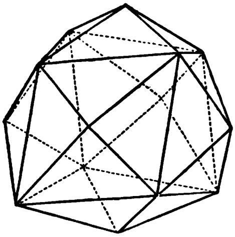


Fig. 17.
Boracite.

52. The Dimetric System (*dis*, twofold, and *metron*, measure) has three axes at right angles to one another. Two of these axes are of equal length, and the third of varying length, as shown in the square prism in Fig. 18, where the vertical axis *a a* is longer than the lateral axes *b b*, *c c*, but in which all these axes are at right angles to one another. The simple forms in this system, the *square prism* and the *square octahedron*, are shown in Figs. 19, 20, and 21.

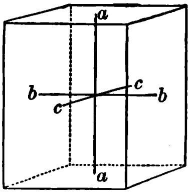


Fig. 18.—Square Prism.

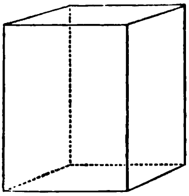


Fig. 19.
Square Prism.

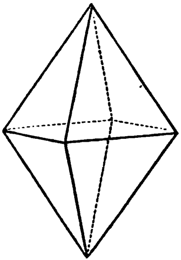


Fig. 20.—Acute Square Octahedron.

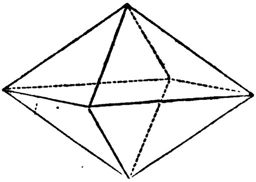


Fig. 21.—Obtuse Square Octahedron.

In the acute square octahedron the vertical axis is longer than the lateral axes; in the obtuse square octahedron the vertical axis is shorter than the lateral axes. These differences are shown in Figs. 20 and 21 respectively.

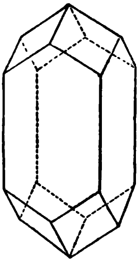


Fig. 22.—Calcium Copper Acetate.

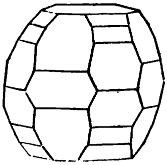


Fig. 23.
Nickel Sulphate.

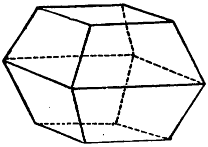


Fig. 24.
Potassium Ferrocyanide.

Some of the modified forms as actually found in chemical substances are shown in Figs. 22, 23, and 24.

53. The Trimetric System (*tris*, threefold, and *metron*, measure) has three axes, all of unequal length, and all at right angles to one another, as seen in Fig. 25, in the rectangular prism, where the axes *a a*, *b b*, and *c c* are all of unequal length, and at right angles to one another. The vertical axis *a a*, may either be longer or shorter than either of the lateral axes *b b*, or *c c*. It cannot, however, be equal to

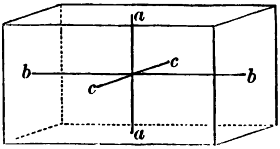


Fig. 25.—The Rectangular Prism.

either of them, since this would produce a right square prism.

The principal forms in this system are the *rectangular prism*, the *rhombic prism*, and the *rhombic octahedron*. They are shown in Figs. 26, 27, and 28.

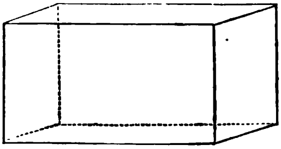


Fig. 26.
Rectangular Prism.

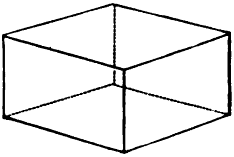


Fig. 27.
Rhombic Prism.

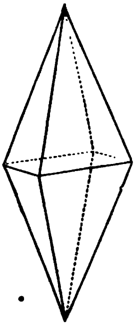


Fig. 28.—Rhombic Octahedron.

Some of the modified forms of this system, as actually found in chemical substances, are shown in Figs. 29, 30, and 31.

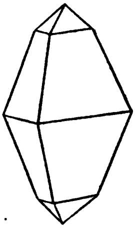


Fig. 29.—Sulphur.

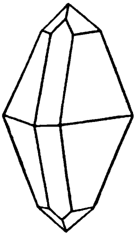


Fig. 30.—Sulphur.

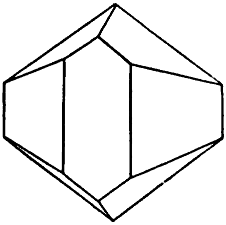


Fig. 31.—Potassium Sulphate.

54. The Monoclinic System (*monos*, one, and *klino*, to incline) has three unequal axes; the two lateral axes *b b*, and *c c*, are at right angles to one another; the vertical axis *a a* is inclined to one of the lateral axes *b b*, and vertical to the other, *c c*. Thus in the oblique rectangular prism, shown in Fig. 32, the vertical axis is inclined to one of the lateral axes, but at right angles to the other.

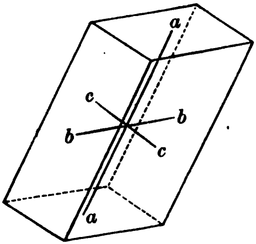


Fig. 32.
Oblique Rectangular Prism.

The principal forms belonging to this system are the *oblique rectangular prism*, the *oblique* *rhombic prism*, and the *oblique rhombic octahedron.* These are shown in Figs. 33, 34, and 35.

In the oblique rectangular prism, the upper and lower bases are rectangles; in the oblique rhombic prism, they are rhombuses.

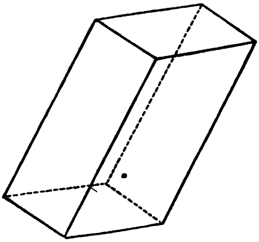


Fig. 33.
Oblique Rectangular Prism.

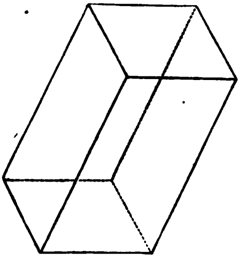


Fig. 34.
Oblique Rhombic Prism.

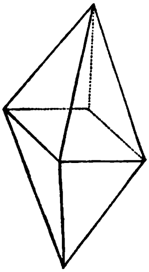


Fig. 35.—Oblique
Rhombic Octahedron.

Some of the modifications of this system, as actually found in chemical substances, are shown in Figs. 36, 37, and 38.

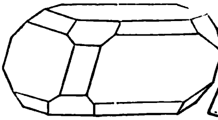


Fig. 36.—Nickel Potassium
Sulphate.

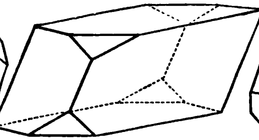


Fig. 37.
Green Vitriol.

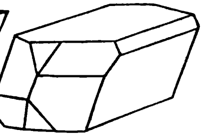


Fig. 38.
Glauber Salts.

55. The Triclinic System (*tris*, three, and *clino*) has three unequal axes, all of which are inclined to one another, as shown in Fig. 39, which represents the one simple form belonging to this system, viz., the *oblique rhomboidal prism.* In this prism the axes *a a*, *b b*, and *c c* are all unequal and inclined.

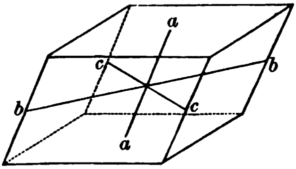


Fig. 39.—Oblique Rhomboidal Prism.

In the oblique rhomboidal prism the upper and lower bases are rhomboids, two of the angles in each being acute, and two obtuse.

Some of the modifications of this system, as actually found in chemical substances, are shown in Figs. 40, 41, and 42.

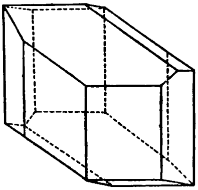


Fig. 40.
Copper Sulphate.

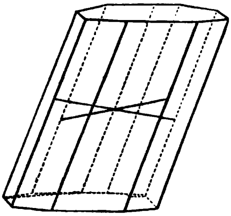


Fig. 41.
Calcium Thio-Sulphate.

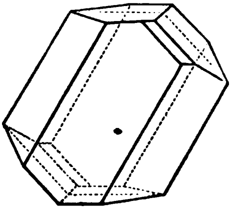


Fig. 42.
Albite.

56. The Hexagonal System has four axes—three equal lateral axes at right angles to a vertical axis, but intersecting one another at 60°, as is shown in Fig. 43, which represents the hexagonal prism, in which the lateral axes *b b*, *c c*, and *d d*, intersect one another at 60°, but are at right angles to the vertical axis *a a*.

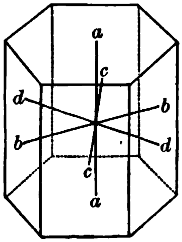


Fig. 43.
Hexagonal Prism.

The principal forms belonging to this system are the *hexagonal prism, the double six-sided pyramid*, sometimes called the hexagonal pyramid, and the *rhombohedron.* They are shown in Figs. 44, 45, and 46.

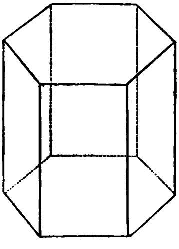


Fig. 44.
Hexagonal Prism.

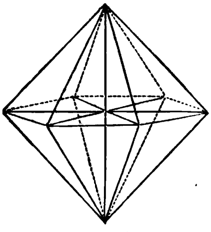


Fig. 45.—The Double Six-sided Prism, called the Hexagonal Pyramid.

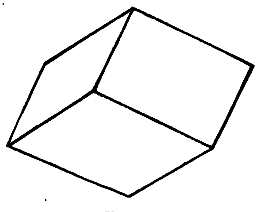


Fig. 46.
The Rhombohedron.

The manner in which the rhombohedron is derived from the hexagonal pyramid is shown in Fig. 47. By extending the alternate planes until they cover the rest, the rhombohedron is obtained. The rhombohedron is, therefore, a hemihedral modification of the hexagonal pyramid. If the modification occur in the other set of alternate planes, another rhombohedron is produced, which differs only in position from that shown in the figure.

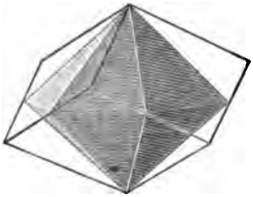


Fig. 47. Derivation of the Rhombohedron.

Some of the modifications of this system, as actually found in chemical substances, are shown in Figs. 48, 49, and 50.

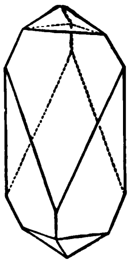


Fig. 48.—Calcspar.

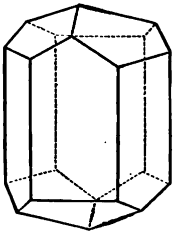


Fig. 49.—Calcspar.

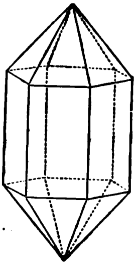


Fig. 50.—Quartz.

57. Isomorphism—Dimorphism.—Though most chemical substances have crystalline forms peculiar to them, yet it has been discovered that identity of crystalline form does not always indicate identity of chemical composition. There are certain elements that can replace one another in a chemical compound without altering its crystalline form. Such substances are said to be *isomorphous* substances (ἰσός, equal, and μορφή, shape).

Very careful measurements show that slight differences exist in the angles of isomorphous crystals; or, in other words, that they are not absolutely identical in form.

Some substances occur in forms belonging to more than one system. Those occurring in the forms of two distinct systems are said to be *dimorphous*.

58. Cleavage—Twin Crystals.—Most crystalline substances are more easily broken in certain directions than in others; this property is called *cleavage.* It is very marked in mica, and in selenite or sulphate of lime; it is also well developed in calcspar or calcium carbonate, and in galena or sulphide of lead.

Occasionally two crystals are united to one another in such a manner as to produce a symmetrical figure; such combinations are called *twin crystals*, an instance of which is seen in Fig. 51, which is one of the forms in which the mineral substance called gypsum occasionally occurs.

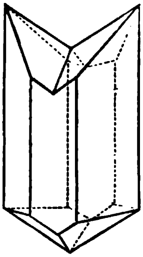


Fig. 51.
Twin Crystals.

SYLLABUS.

All solid substances occur in either the crystalline or in the amorphous condition.

A crystalline solid is one bounded by symmetrically arranged plane faces. An amorphous solid is one in which no traces of crystalline structure are discernible.

In order that a solid may assume the crystalline form, its molecules should have freedom of motion at the moment they are assuming the solid state. This freedom of motion may be obtained, 1st. By dissolving the solid in some liquid; 2d. Melting or fusing the solid by heat; 3d. By sublimation; 4th. By chemical decomposition or precipitation, and 5th. By electrical decomposition or precipitation.

The face of a crystal is the plane surface that bounds it. The edge is the line formed by the intersection of two adjacent faces. The solid angles are at the points where the three or more intersecting faces meet.

The faces of a crystal are similar when they have the same form in similar positions. They are dissimilar when their form is different in similar positions.

The form of a crystal is subject to modification by having its edges or faces cut or replaced by one or more planes. Such modifications are called holohedral, when all the edges or angles are modified, and hemihedral, when only the alternate edges or angles are modified.

The axes of a crystal are imaginary lines passing through the centre of the crystal and terminating in the centres of the opposite faces, edges, or angles.

There are six systems or types of crystals, viz.: 1st. The Monometric system, sometimes called the isometric or cubic; 2d. The Dimetric system, sometimes called the quadratic or square prismatic; 3d. The Trimetric system, sometimes called the rhombic; 4th. The Monoclinic system, sometimes called the oblique rhombic; 5th. The Triclinic system, sometimes called the oblique rhomboidal; and 6th. The Hexagonal system, sometimes called the rhombohedral.

The monometric system has but one measure for the axes; that is, they are all of equal length, and are at right angles to one another. This system includes the cube, the regular octahedron, and the rhombic dodecahedron.

The dimetric system has two different measures for the axes. Only two of the axes are of the same length; the third is of a different length. The axes are all at right angles to one another. This system includes the square prism, and the square octahedron.

The trimetric system has three measures for the three axes, which are all of unequal length, but are all at right angles to one another. This system includes the rectangular prism, the rhombic prism, and the rhombic octahedron.

The monoclinic system has three unequal axes—two lateral axes at right angles to each other, and one vertical axis, inclined to one of the lateral axes, but at right angles to the other. This system includes the oblique rectangular prism, the oblique rhombic prism, and the oblique rhombic octahedron.

The triclinic system has three unequal axes, all inclined to one another. It includes the oblique rhomboidal prism.

The hexagonal system has four axes—three lateral axes of the same length, intersecting one another at 60°, and a fourth vertical axis, of different length from the lateral axes, and at right angles to all of them. This system includes the hexagonal prism, the double six-sided pyramid, and the rhombohedron.

Substances are said to be isomorphous when they are capable of replacing others in a crystalline compound without altering the crystalline form.

Substances that crystallize in forms belonging to more than one distinct system are said to be dimorphous.

By the cleavage of a crystal is meant the direction in which it readily splits or breaks.

Twin crystals are two distinct crystals united so as to form a symmetrical solid.

QUESTIONS FOR REVIEW.

Distinguish between a crystalline and an amorphous substance.

Enumerate all the conditions favorable to crystallization.

Define face of a crystal; edge of a crystal; solid angle of a crystal.

When are the faces of a crystal said to be similar? When are they said to be dissimilar?

Explain the different ways in which the shape of a crystal may undergo modification.

Distinguish between a holohedral and hemihedral modification.

Name the different systems of crystals.

Describe the monometric system, and name the simple forms that belong to it.

Describe the dimetric system, and name the simple forms that belong to it.

Describe the trimetric system, and name the principal forms that belong to it.

Describe the monoclinic system, and name the principal forms that belong to it.

Describe the triclinic system, and name the only simple form that belongs to it.

Describe the hexagonal system, and name the simple forms that belong to it.

To which system does each of the following forms belong, viz.: the rhombohedron; the tetrahedron; the oblique rhombic prism; the regular octahedron; the square octahedron; the rhombic octahedron; the hexagonal prism?

Define isomorphism; dimorphism; cleavage, and twin crystals.

PART II.—DESCRIPTIVE AND EXPERIMENTAL CHEMISTRY.

THE NON-METALS.

SECTION I.

HYDROGEN AND THE HALOIDS.

CHAPTER I.

CLASSIFICATION OF THE NON-METALLIC ELEMENTS.
HYDROGEN.

59. Classification of the Non-Metallic Elements.—The elements are divided into two classes, viz., the non-metals and the metals. The non-metals include hydrogen, chlorine, bromine, iodine, fluorine, oxygen, sulphur, selenium, tellurium, nitrogen, phosphorus, boron, arsenic, antimony, carbon, and silicon. All the rest are metals.

The non-metals may be conveniently arranged in four distinct groups, according to their quantivalence. These groups are based on the composition of the volatile compounds which the non-metallic elements form with hydrogen. They are as follows, viz.:

I.	II.	III.	IV.
Hydrogen.	Oxygen.	Nitrogen.	Carbon.
Chlorine.	Sulphur.	Phosphorus.	Silicon.
Bromine.	Selenium.	Boron.	
Iodine.	Tellurium.	Arsenic.	
Fluorine.		Antimony.	
		Bismuth.	

60. Molecular Types of the Non-Metallic Elements.—Each of the preceding groups produces a distinct type of molecular structure by the combination of any of its members with hydrogen, viz.:

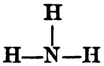
Monadic Type.

H—H	H—Cl	H—Br	H—I	H—Fl
Hydrogen.	Hydrogen Chloride.	Hydrogen Bromide.	Hydrogen Iodide.	Hydrogen Fluoride.

Dyadic Type.

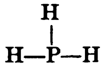
H—O—H	H—S—H	H—Se—H	H—Te—H
Water.	Hydrogen Sulphide.	Hydrogen Selenide.	Hydrogen Telluride.

Triadic Type.



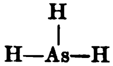
$$\begin{array}{c}\mathrm{H}\\ | \\ \mathrm{H{-}N{-}H}\end{array}$$

Ammonia.



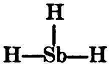
$$\begin{array}{c}\mathrm{H}\\ | \\ \mathrm{H{-}P{-}H}\end{array}$$

Phosphoretted Hydrogen.



$$\begin{array}{c}\mathrm{H}\\ | \\ \mathrm{H{-}As{-}H}\end{array}$$

Arseniuretted Hydrogen.

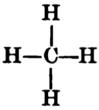


$$\begin{array}{c}\mathrm{H}\\ | \\ \mathrm{H{-}Sb{-}H}\end{array}$$

?

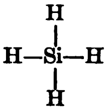
Hydrogen Antimonide.

Tetradic Type.



$$\begin{array}{c}\mathrm{H}\\ | \\ \mathrm{H{-}C{-}H}\\ | \\ \mathrm{H}\end{array}$$

Marsh Gas.



$$\begin{array}{c}\mathrm{H}\\ | \\ \mathrm{H{-}Si{-}H}\\ | \\ \mathrm{H}\end{array}$$

Siliciuretted Hydrogen.

HYDROGEN.

H = 1. Density = 1. Compared with air = 0.0693. Molecular weight = 2. Quantivalence = 2. Free molecule, H—H. Discovered by Cavendish in 1776.

61. Occurrence in Nature.—Hydrogen exists in nature in combination only.

To this general statement we may except its occasional occurrence in a free state in the emanations from volcanoes or oil-wells, or its association with certain meteoric masses. It exists in immense masses in the interstellar spaces.

Hydrogen is one of the elements of water, of which it constitutes one-ninth part by weight. Either in the form of water, or combined with oxygen, sulphur, carbon, or nitrogen, it enters largely into the composition of plants and animals.

62. Preparation.—Hydrogen is most conveniently prepared by the action of sulphuric acid on metallic zinc or iron.

Experiment 1.—Place some scraps of metallic zinc in the two-necked bottle, B, Fig. 52, which is partly filled with water. Connect the funnel-tube, S, with one neck, and the delivery-tube, P, with the other neck. Then pour some sulphuric acid in the funnel-tube, S, and hydrogen will be immediately liberated. When the disengagement of gas has continued for a few minutes, place the free end of the delivery-tube under the lower end of the jar, C, filled with water, and supported on the shelf, H, of the pneumatic trough, T. The gas will pass in bubbles through the water in C, and will gradually displace it.

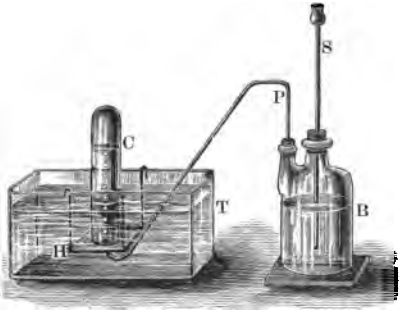


Fig. 52.—Preparation of Hydrogen.

Description of the Apparatus.—The two-necked bottle, B, is called a *Wolfe Bottle.* These bottles are sometimes furnished with more than two necks.

The *funnel-tube,* S, affords a convenient mode of introducing a liquid into a bottle without allowing the air to enter the bottle, or the gas it contains to escape. This it does by the lower end of the tube dipping below the surface of the liquid. It also acts as a *safety-tube;* for, should the delivery-tube become stopped, the continued evolution of gas will not burst the bottle or blow out the corks, since then the pressure of the gas acting on the surface of the liquid, causes it to mount in the tube, S, and even to escape from the funnel-mouth.

The *delivery-tube,* P, is most conveniently arranged by slipping a gum tube over the upper end of a short glass tube.

To prevent the escape of gas from the necks of the bottle, the tubes should fit the corks tightly, and the latter be firmly inserted in the necks. Any size hole is readily made in the cork by a *cork-borer.*

The tank, T, which is filled with water, and has a perforated shelf, H, placed below the water surface, is called a *pneumatic trough.*

The *collecting-jar,* C, is first filled with water, and then covered by the hand and inserted below the surface of water in the tank, and placed upright on the shelf, H. As the gas rises to the top of C, it gradually displaces the water, and at last completely fills the jar. To remove the jar from the trough, it is slipped from the shelf to a shallow dish partially filled with water.

In the preparation of hydrogen by metallic zinc the reaction may be thus expressed:

$$\underset{\text{Zinc}}{Zn} + \underset{\text{Sulphuric Acid}}{H_2SO_4} = \underset{\text{Zinc Sulphate}}{ZnSO_4} + \underset{\text{Hydrogen.}}{H_2}$$

63. Preparation by Metallic Sodium.—Hydrogen may be readily obtained by the action of metallic sodium on water.

Experiment 2.—Place a few small pieces of metallic sodium on a spoon, S, Fig. 53, below a jar, J, filled with water. The spoon is covered with wire gauze, in order to prevent the sodium from rising through the water. A brisk disengagement of gas ensues, which bubbles through the water into J, displacing the water therein.

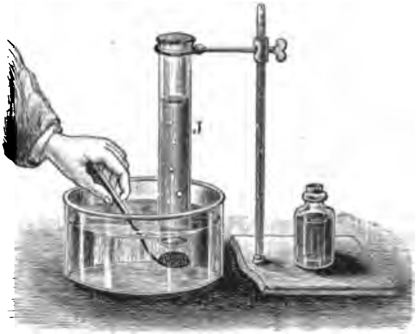


Fig. 53.—Preparation by Metallic Sodium.

The reaction in this case is as follows, viz.:

$$\underset{\text{Water}}{2H_2O} + \underset{\text{Sodium}}{Na_2} = \underset{\text{Sodium Hydrate}}{2NaOH} + \underset{\text{Hydrogen.}}{H_2}$$

64. Physical Properties.—Hydrogen is a colorless, tasteless, and inodorous gas. It is the lightest of all known bodies, being 14.44 times lighter than common air. The small rubber balloons sold for toys owe their buoyancy to being filled with hydrogen.

Under the combined influence of excessive pressure and cold, hydrogen becomes converted into a liquid.

Experiment 3.—Attach a common clay pipe to the rubber delivery-tube of Fig. 52, and, dipping the pipe in soapy water, allow the escaping gas to blow bubbles. Observe that these are very light, and rise more rapidly through the air than would bubbles blown with the breath.

Hydrogen possesses marked powers of diffusion. That is, it passes rapidly through animal and vegetable membranes, and through many bodies that are impervious to water.

If a jar, filled with hydrogen, be placed mouth downwards over a jar filled with oxygen, it will gradually mix therewith, the lighter hydrogen passing downwards into the oxygen.

Experiment 4.—Fix a broad cork in the mouth of an unglazed earthenware jar, J, Fig. 54, and pass a glass tube, T, through the cork. Then properly support the two, and place as shown in the figure, with the lower end of T beneath the surface of water in the vessel V. If now a bell-shaped jar, B, filled with hydrogen, be held over J, as shown, the lighter hydrogen enters by diffusion more rapidly into the jar than the air passes out, and bubbles of gas will be seen escaping through the liquid in V. On removing the jar, B, a partial vacuum, caused by the rapid diffusion of the hydrogen out from the jar, J, causes a rise of the liquid in T.

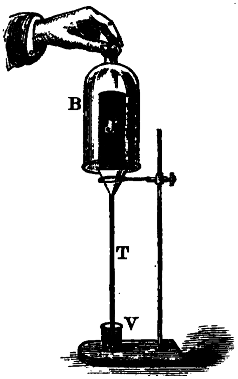


Fig. 54.
Diffusion of Hydrogen.

65. Occlusion of Hydrogen.—Certain substances, especially the metals and carbon, possess the property of absorbing hydrogen and condensing it within their pores. Hydrogen is absorbed so rapidly by red-hot iron and platinum, that it can readily pass through heated plates of these metals. Palladium absorbs hydrogen with very remarkable energy, condensing as much as nine hundred times its own volume of the gas.

The name *occlusion* has been given to the property possessed by various substances of absorbing and condensing hydrogen.

The passage of hydrogen through heated metallic plates is believed to be attended with an actual liquefaction of the gas at one surface of the metallic plate and its re-evaporation at the other.

The free hydrogen, found in meteorites, is most probably occluded hydrogen, absorbed by these bodies during their passage through the huge masses of hydrogen that the spectroscope shows exist in interstellar space. The quantity of gas found in a meteorite, in proportion to its volume, seems to indicate the existence of greater gaseous pressures in these masses of hydrogen than exist in our atmosphere; that is, of pressures at the level of the sea, greater than fifteen pounds to the square inch.

66. Chemical Properties.—Hydrogen burns freely in air, with the production of the vapor of water. Its combinations with metals and organic radicals are called *hydrides*. It may, if pure, be breathed with safety, but if associated with but small quantities of arsenic is highly poisonous. Since hydrogen is univalent, it cannot exist in a free state. Its molecule is H—H.

Experiment 5.—Hydrogen is freely combustible in air.

Remove the jar, C, filled with hydrogen from a pneumatic trough, and, holding it as shown in Fig. 55, apply a lighted taper to the open end. An ignition of the gas at once ensues, a pale blue flame appearing at the mouth of the jar. Insert the taper into the jar and observe that its flame is at once extinguished. Draw it slowly out, and observe that it is relighted. This may be repeated several times.

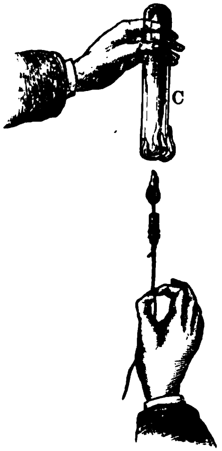


Fig. 55.
Experiment showing the Combustibility of Hydrogen.

Experiment 6.—Hydrogen, when mixed with air, burns explosively on the approach of a flame.

Place some soapsuds in a shallow saucer, S, Fig. 56, and blow a mass of bubbles with hydrogen that has been mixed with air, by collecting hydrogen in a jar already partly filled ($\frac{5}{7}$ full) with air. On touching this mass with a lighted taper, a violent though harmless explosion ensues.

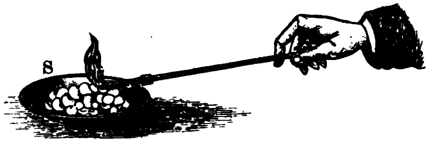


Fig. 56.
Experiment showing the Explosiveness of H and O.

An excellent illustration of the harmlessness of such explosions may be obtained by holding a mass of the bubbles in the open hand, and exploding them therein. If the hand is kept open no harm results. Such explosions, however, occurring in closed vessels are very dangerous. Great care should be taken to avoid the mixing of air with hydrogen. Before attempting to light a large bulk of the gas, a small quantity should always be previously passed into a jar, and tested by a flame.

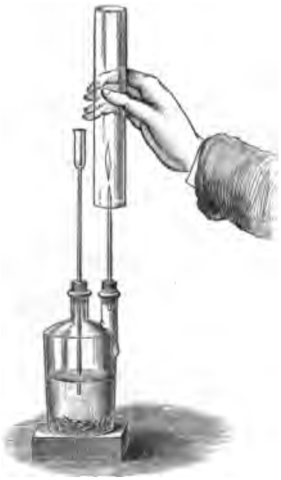


Fig. 57.—Production of Musical Note by Jet of Burning Hydrogen.

Experiment 7.—These explosions may be made to produce a musical sound. Arrange a hydrogen bottle, with a glass tube drawn into a jet for the delivery-tube, as shown in Fig. 57. Pour the acid on the zinc, and, after waiting long enough to have all the air driven from the bottle, light the jet of escaping gas; it will burn with a pale blue flame. Now hold an open glass tube over the jet in the manner shown, and a clear musical note will be heard. Unless sufficient time is given to insure all the air being driven from the tube, the ignition of the gas at the jet will result in an explosion of the mixed air and gas in the bottle, which may produce serious results.

Experiment 8. – Hydrogen, when burned in air, forms the vapor of water. Connect the hydrogen bottle, H, Fig. 58, by a suitable delivery-tube, with a tube, T T, filled with calcium chloride, a substance that will dry gases passing over it, by reason of the great attraction that calcium chloride has for water. Connect the other end of the tube, T T, with a delivery-tube, *b b*, and pouring acid in the safety-tube, S, in a few minutes a stream of dry hydrogen will flow from the open end of *b b*. Now light this, and holding the jar, D, above the flame, observe that water is condensed on the side of the jar and may be collected in a plate placed below it.

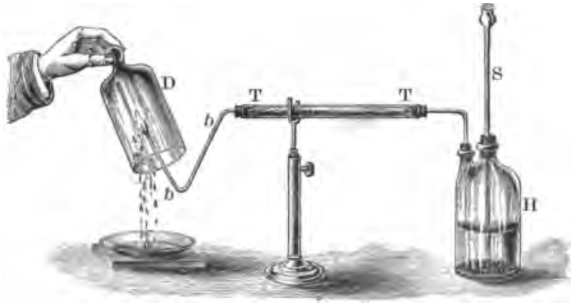


Fig. 58.—Production of Water by Combination of Hydrogen in Air.

CHAPTER II.

CHLORINE, BROMINE, IODINE, AND FLUORINE.

THIS group is sometimes called the Haloid group, *i. e.*, the salt-formers.

CHLORINE.

Cl = 35.5. Density = 35.5. Compared with air = 2.46. Molecular weight = 71. Quantivalence = I., III., V., VII. Free molecule, Cl—Cl. Discovered by Scheele in 1774.

67. Occurrence in Nature.—Chlorine does not exist in a free state in nature. Its principal source is in common salt, which is a combination of sodium and chlorine. In this form it occurs in large quantities in sea-water, and in extensive beds of rock-salt. It also exists in various chlorides, both in the organic and inorganic kingdoms.

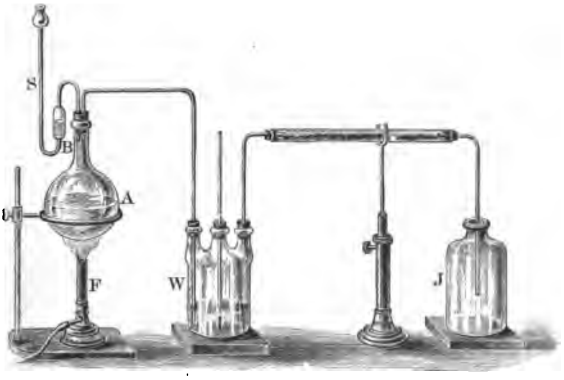


Fig. 59.—Preparation of Chlorine.

68. Preparation.—Chlorine is most conveniently prepared by the action of hydrochloric acid on manganese dioxide.

Apparatus suitable for the preparation of chlorine by this method is shown in Fig. 59.

Experiment 9.—Place one part of manganese dioxide (black oxide of manganese) in coarse powder, in the flask A, Fig. 59, and add to it, through the safety-tube, S, six parts of hydrochloric acid. This safety-tube is furnished with a bend and bulb at B, which retains a part of the acid poured in at S, and thus seals the tube. The gas is evolved in the cold. A more rapid evolution may be obtained by means of a gentle heat furnished by the burner, F.

The gas, after being washed by passing through a little water in the Wolfe bottle, W, called, when used for this purpose, a *wash-bottle*, and then dried by passing through the calcium chloride tube, may be collected in a narrow-necked jar, J, by *simple displacement*. That is to say, the delivery-tube is carried to the bottom of the jar, J, when the gas, owing to its greater density, gradually fills the jar by displacing the air.

The reaction which occurs may be expressed as follows:

$$MnO_2 + 4HCl = 2H_2O + MnCl_2 + Cl_2$$

$$\text{Manganese Dioxide} + \text{Hydrochloric Acid} = \text{Water} \quad \text{Manganese Chloride} + \text{Chlorine.}$$

69. Physical Properties.—Chlorine is a transparent gas of a greenish-yellow color, and a highly disagreeable, suffocating odor. When breathed in moderately large quantities it produces violent coughing, together with inflammation of the eyes, nose, and throat. At ordinary temperatures, chlorine is liquefied by a pressure of about four atmospheres (*i. e.*, 4 times 15 pounds to the square inch). Liquid chlorine has a yellow color.

Chlorine gas is soluble in about one-half its volume of cold water.

70. Chemical Properties.—Chlorine has very energetic affinities. It combines directly with most of the other elements. Its compounds with the metals are called chlorides. Finely divided antimony, arsenic, zinc, or phosphorus take fire spontaneously, when dropped into a jar full of pure chlorine.

Chlorine possesses so powerful an affinity for hydrogen that it decomposes most all the compounds of hydrogen. Since nearly all organic coloring matters contain hydrogen, clothes or other fabrics dyed therewith, are bleached by exposure to chlorine. Considerable practical use is made of this property.

Besides its direct combination with the hydrogen of the coloring matter, chlorine owes its bleaching properties to the fact that it decomposes water, combining with its hydrogen and liberating its oxygen, which latter gas, in the nascent state, that is when just liberated, oxidizes and destroys the coloring matter. In bleaching, therefore, with chlorine, the fabrics should be moist.

The disinfecting properties of chlorine are to be explained in the same manner, by the decomposition of the offensive or unwholesome vapors, owing to the removal of their hydrogen.

Experiment 10.—Dip a piece of tissue-paper in oil of turpentine (a compound of carbon and hydrogen) and drop it in a jar, J, Fig. 60, filled with chlorine. The chlorine at once combines violently with the hydrogen of the turpentine, igniting the paper, and liberating the carbon as a dense black cloud. The turpentine for this experiment should be kept protected from the air.

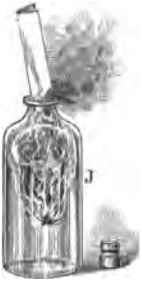


Fig. 60.
Combustion of Turpentine in Chlorine.

Experiment 11.—Introduce into a jar of chlorine, a strip of moistened calico. Observe that the colors gradually disappear, the calico becoming of a uniform whitish color.

Experiment 12.—Take any printed card and blacken with writing ink so as to render the letters invisible. Moisten with water and introduce into a jar of chlorine. The inked letters will then appear as if by magic—the chlorine bleaching the writing ink, but not touching the carbon ink.

Chlorine will support combustion. If a lighted candle be introduced into a jar of the gas, it will burn with a smoky red flame.

* * *

Hydrochloric Acid.

Density = 18. Compared with air = 1.247. Molecular weight = 36.5. Discovered by Priestley in 1772.

71. Occurrence and Preparation.—Hydrochloric acid occurs in a free state in gaseous emanations from volcanoes.

It is most conveniently prepared by the action of strong sulphuric acid on common salt. The gas is soluble in water, and is therefore collected over mercury or by displacement. The reaction is as follows:

$$\underset{\text{Sulphuric Acid}}{H_2SO_4} + \underset{\text{Sodium Chloride}}{NaCl} = \underset{\text{Acid Sodium Sulphate}}{NaHSO_4} + \underset{\text{Hydrochloric Acid.}}{HCl}$$

Hydrochloric acid may also be formed by the direct union of the two gases. Equal volumes of these gases when mixed together, and exposed to direct sunlight, combine explosively without contraction of volume.

The hydrochloric acid of commerce, commonly called muriatic acid, is a saturated solution of hydrochloric acid gas in water. It may be prepared by passing the gas through a number of Wolfe bottles, A, B, and C, Fig. 61, partly filled with water. The impurities collect in the first bottle, A. The common salt and sulphuric acid are introduced into the flask F, the reaction being aided by heat.

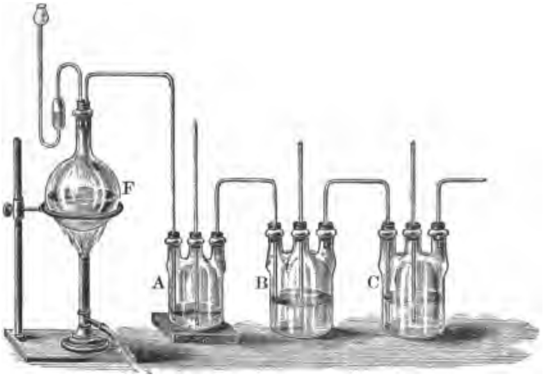


Fig. 61.—Preparation of Hydrochloric Acid.

72. Physical Properties.—Hydrochloric acid is a colorless gas, with a disagreeable, pungent smell. It is readily condensed by cold and pressure into a colorless liquid. Hydrochloric acid gas is very soluble in water. A bottle filled with the gas, and dipped mouth downwards in water, when the cork is removed, is almost instantly filled with water, so rapid is the absorption of the gas. At the temperature of the freezing-point, water absorbs five hundred times its own volume of the gas.

73. Chemical Properties.—Hydrochloric acid has strong acid properties, reddening vegetable blues. It forms chlorides with the metals, by the replacement of its hydrogen by the metallic substance.

Experiment 13.—Pour into a glass jar a solution of litmus, or purple cabbage. Add to it a few drops of hydrochloric acid, and stir with a glass rod. Observe that the blue color is at once changed into a red.

The above is the simplest test for the presence of an acid substance. The acid may either be added directly to the blue litmus solution, or paper may be colored blue by steeping it in the solution. *Blue litmus paper* thus prepared, is dipped directly into any liquid in order to test it. The paper must be kept in the dark, and in a tightly-stoppered bottle, to avoid reddening by acid fumes.

* * *

BROMINE.

Br = 80. Density of vapor = 80. Compared with air = 5.54. Sp. gr. of liquid at 32° F. = 3.187. Boiling-point = 145°. 4 F. Molecular weight = 160. Quantivalence = I., V., VII. Free molecule, Br—Br. Discovered by Balard in 1826.

74. Occurrence and Preparation.—Bromine does not exist in a free state in nature. It is found in combination only, in the form of bromides.

Bromine is most conveniently prepared by the action of sulphuric acid and manganese dioxide on any bromide, such as potassium bromide. The liquor that remains after the crystallizable salts have been extracted from sea-water, being rich in bromides, is generally employed for this purpose.

When potassium bromide is employed, the reaction is as follows, viz.:

$$\underset{\text{Potassium Bromide}}{2KBr} + \underset{\text{Manganese Dioxide}}{MnO_2} + \underset{\text{Sulphuric Acid}}{2H_2SO_4} = \underset{\text{Potassium Sulphate}}{K_2SO_4} +$$

$$\underset{\text{Manganese Sulphate}}{MnSO_4} + \underset{\text{Water}}{2H_2O} + \underset{\text{Bromine.}}{Br_2}$$

75. Properties of Bromine.—At ordinary temperatures bromine is a heavy, mobile liquid, of a nearly opaque, dark red color. It is the only element, except mercury, that is liquid at ordinary temperatures. It has a very unpleasant smell, its name (*βρῶμος*, stench) arising from this property. Its odor is suffocating. When inhaled, it irritates the throat and eyes; when touched to the skin, it produces corrosive sores that are difficult to heal. Some of the bromides are of great value in medicine and in photography. Bromine is soluble in ether.

Experiment 14.—Into a long tube, closed at one end, pour a small quantity of potassium bromide. Then nearly fill the tube with water in which chlorine has been dissolved. Mix the solution and observe the orange red color of the liberated bromine. Now add a small quantity of ether, and, after briskly shaking, observe that when the ether has collected on the surface of the water it has been colored a dark red, from having dissolved the bromine.

76. Hydrogen Bromide or Hydrobromic Acid.—Bromine combines with hydrogen to form hydrobromic acid, a substance analogous in composition to hydrochloric acid. Hydrobromic acid is a colorless gas; it has an irritating smell and reddens blue litmus paper.

◆

IODINE.

I = 127. Density of vapor = 127 nearly. Compared with air = 8.71. Molecular weight = 254. Quantivalence = I., III., V., VII. Free molecule, I—I. Sp. gr. of solid = 4.94. Melts at 239° F. Discovered by Courtois in 1811.

77. Occurrence in Nature.—Iodine does not exist in a free state in nature, but in combination, as iodides, is widely diffused. Its principal source is in sea-water and various marine animals and plants.

78. Preparation.—Iodine is prepared commercially from sea-weeds, especially from the deep water variety. The weed is burned, and the ashes, known in commerce as *kelp*, are steeped in boiling water, which dissolves out all their soluble salts. The solution is then allowed to crystallize, so as to separate all the crystallizable salts. The liquor which remains, and which is called the *mother liquor*, contains various iodides and bromides.

Most of the kelp of commerce comes from the coasts of Great Britain and France. During the stormy spring months, the sea-weed is thrown in large quantities on the shore. It is collected in large heaps, dried, and burned.

Various processes are employed for the separation of the iodine from the kelp. One of these consists in the decomposition of the iodides by nitric acid, in which case the reaction may be represented as follows, viz.:

$$\underset{\text{Nitric Acid}}{4HNO_3} + \underset{\text{Potassium Iodide}}{2KI} = \underset{\text{Potassium Nitrate}}{2KNO_3} + \underset{\text{Nitrogen Dioxide}}{2NO_2} + \underset{\text{Water}}{2H_2O} + \underset{\text{Iodine.}}{I_2}$$

The iodine vapor given off in the above process condenses on the top and sides of cooled vessels in crystalline scales.

79. Properties of Iodine.—Iodine is a shining, opaque, crystalline solid of a dark gray color. It is readily converted by heat into a vapor of a deep violet color. It imparts a yellow stain to the skin. Its smell somewhat resembles that of chlorine and bromine, but is less offensive. It dissolves readily in alcohol and ether, giving a dark-brown color to the liquid. This alcoholic solution forms the well-known *tincture of iodine* of the apothecaries. Iodine is extensively used in photography as various iodides.

Experiment 15.—Place a few crystals of iodine in a glass flask (called a *Florence flask*, made of thin glass, so as to stand heat without breaking), and gently heat it. A rich violet-colored vapor of iodine will form, which, on cooling, deposits minute crystals of iodine on the sides of the glass.

The conversion of a solid into a vapor, and the subsequent condensation of the vapor, is called *sublimation*.

Experiment 16.—Place in a tall jar, a weak, boiled solution of common starch, and add thereto a drop of tincture of iodine. A deep blue coloration ensues.

Starch solution forms a delicate test for iodine. A few drops of the liquid, supposed to contain iodine, are added to the starch solution. If the iodine is in combination, it is liberated by a few drops of chlorine water.

80. Hydrogen Iodide, or Hydriodic Acid.—Iodine combines with hydrogen and forms a colorless gas possessing acid properties. This gas is called hydriodic acid. It is comparatively unimportant.

◆

FLUORINE.

Fl = 19. Quantivalence = I. Free molecule, Fl—Fl.

81. Occurrence in Nature and Preparation.—Fluorine occurs in nature in combination only. Its principal source is found in the mineral called fluor-spar, which is a combination of calcium and fluorine.

Fluorine possesses such energetic affinities that it has never been isolated, since it attacks and combines with any vessel into which it might be placed. Consequently, nothing is actually known of its vapor density. Its most important compound, with the exception of the native fluorides, is that with hydrogen, viz.: hydrogen fluoride.

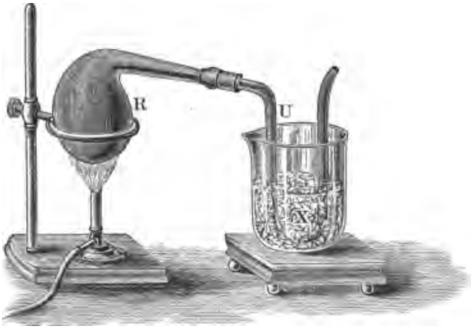


Fig. 62.—Preparation of Hydrofluoric Acid.

82. Hydrogen Fluoride, or Hydrofluoric Acid.—Hydrofluoric acid is prepared by the action of sulphuric acid on calcium fluoride. The fluor-spar is powdered, and placed with sulphuric acid, in a leaden retort, R, Fig. 62, connected with a leaden U-shaped tube, U, surrounded by a *freezing mixture*, X; that is, a mixture of salt, with snow or fragments of ice. A very gentle heat liberates the hydrofluoric acid, which is condensed in the tube U by the cooling effects of the freezing mixture.

The reaction may be represented as follows, viz.:

$$\begin{array}{ccccccc} CaFl_2 & + & H_2SO_4 & = & CaSO_4 & + & 2HFl \\ \text{Calcium} & & \text{Sulphuric} & & \text{Calcium} & & \text{Hydrofluoric} \\ \text{Fluoride} & + & \text{Acid} & = & \text{Sulphate} & + & \text{Acid.} \end{array}$$

83. Properties of Hydrofluoric Acid.—This substance possesses intensely corrosive, acid properties, and requires to be handled with extreme caution. Its chief use is for etching or cutting designs on glass, which it rapidly corrodes. The glass is coated with a thin layer of wax, and the design made on the glass by removing the wax from the points which it is desired that the acid shall attack. The glass is then washed with a solution of the acid in water.

This process of etching is now almost entirely superseded by the *sand-blast process*. Fine particles of sand are driven by a blast of steam or air against the glass or stone to be cut. A paper stencil of the design, placed over the surface to be cut, permits the sand to act only on the portions exposed.

Experiment 17.—Place a mixture of powdered fluor-spar and sulphuric acid in a shallow leaden dish; coat a plate of glass with a thin layer of white wax, and, with a fine metallic point, trace any design thereon; place the glass plate, with the waxed surface downwards, over the dish so as to cover it; gently heat the dish for a few moments, avoiding the melting of the wax, and then remove the heat and allow the plate to remain over the dish for about ten minutes. On removing the wax from the plate, by scraping and washing in turpentine, it will be observed to be corroded wherever it was not protected by the wax.

SYLLABUS.

The non-metallic elements may be conveniently arranged under four groups according to their combinations with hydrogen. These groups are as follows, viz.: chlorine, bromine, iodine, and fluorine; oxygen, sulphur, selenium, and tellurium; nitrogen, phosphorus, boron, arsenic, and antimony; and carbon and silicon.

Each of the preceding classes, produces a distinct type of molecular structure by the combination of any of its members with hydrogen. These types may be distinguished as the monadic, the diadic, the triadic, and the tetradic types.

Hydrogen, in combination, occurs in water, of which it constitutes one-ninth part by weight. It also enters largely into the composition of all plants and animals.

Hydrogen is, in rare instances, found naturally in a free state, in the gaseous emanations from volcanoes or oil wells, or condensed in meteoric masses.

Hydrogen is most conveniently prepared by the action of sulphuric acid on metallic zinc or iron.

When sulphuric acid is added to metallic zinc, zinc sulphate is formed and hydrogen is liberated. The hydrogen may be collected in a jar filled with water and placed in a pneumatic trough. It may also be collected by simple displacement.

Hydrogen is a colorless, tasteless, and inodorous gas. It is the lightest of all known substances, being 14.44 times lighter than air.

Many substances possess the property of absorbing hydrogen and condensing it within their pores. Palladium can absorb nine hundred times its volume of hydrogen. This property is called occlusion.

Hydrogen burns freely in air, but does not support ordinary combustion. It combines with the metals, and with organic radicals, and forms bodies called hydrides.

Hydrogen, being a monad, cannot exist in the free atomic state. Its free molecule is H—H.

When hydrogen is mixed in certain proportions with air, the mixture explodes violently on contact with a flame.

Water is the sole product of the combustion of hydrogen in air.

Chlorine, bromine, iodine, and fluorine, form a group of elements called the haloids, or salt-formers.

Chlorine exists in nature in a state of combination only. Its commonest and most widely distributed compound is sodium chloride, or common salt.

Chlorine is most conveniently prepared by the action of hydrochloric acid on manganese dioxide.

Chlorine is a transparent gas of a greenish-yellow color, and suffocating odor. Under a pressure of four atmospheres it is liquefied.

Chlorine possesses very energetic affinities. Many of the metals combine so energetically with it as to produce luminous heat. Its combinations with the metals are called chlorides.

Chlorine owes its bleaching properties both to its combination with the hydrogen of organic coloring matters, and to the liberation of oxygen from the decomposition of water.

Chlorine supports combustion by combining with the hydrogen and setting free the carbon of most combustible bodies.

The combination of hydrogen with chlorine forms hydrochloric acid.

This compound is most conveniently prepared by the action of strong sulphuric acid on common salt.

Hydrochloric acid gas is freely soluble in water. The hydrochloric acid of commerce is in reality a saturated solution of the gas in water.

Hydrochloric acid gas is colorless, and has a disagreeable, pungent smell. It possesses strong acid properties and readily reddens vegetable blues.

Bromine occurs in nature in combination only. It is generally obtained by the action of sulphuric acid and manganese dioxide on the residue of the evaporation of sea-water.

At ordinary temperatures, bromine is a heavy, mobile, and nearly opaque, dark red liquid. It has a very disagreeable smell, and derives its name from this circumstance. Its vapor is suffocating, highly corrosive and poisonous.

The compounds of bromine with the metals are called bromides. Some of them are extensively used in medicine and in photography.

Bromine combines with hydrogen and forms a gaseous substance called hydrobromic acid.

Iodine occurs in nature in combination only. Its principal source is found in certain marine animals and plants.

The iodine of commerce is prepared from a certain variety of deep-sea weed. The weed is dried and burned, and the ashes, or kelp, treated with water. The solution so formed is allowed to crystallize, and the mother liquor which remains, is subsequently treated for the iodine and bromine it contains.

Iodine is a shining, opaque, crystalline solid of a dark gray color. When heated, it forms a vapor of a deep violet color. Its smell somewhat resembles chlorine, but is less disagreeable. It dissolves readily in alcohol or ether.

The conversion of a solid into a vapor, and its subsequent condensation, is called sublimation.

Iodine combines with hydrogen and forms a gaseous, acid substance called hydriodic acid.

Fluorine exists in nature in combination only. Its principal source is fluor-spar, a combination of calcium and fluorine.

Fluorine has never been isolated. Its chemical affinities are so energetic that no material can readily be found to contain it.

Fluorine and hydrogen unite to form a compound called hydrofluoric acid. This acid is highly corrosive, and is employed to etch glass.

QUESTIONS FOR REVIEW.

Name the non-metallic elements. Under what four groups may they be arranged? Upon what is this classification founded?

Give an example of each of the types of molecular structure formed by the combinations of the members of each of these groups with hydrogen.

Name some of the principal natural sources of hydrogen in combination. Under what circumstances does hydrogen occur naturally in a free state?

Explain the method of preparing hydrogen by the action of sulphuric acid on metallic zinc. By the action of metallic sodium on water.

Describe the shape of a Wolfe bottle. Explain the use of a safety-tube. What other form may the safety-tube have? Explain the use of a pneumatic trough in the collecting of hydrogen.

Write the reaction for the preparation of hydrogen by the action of sulphuric acid on metallic zinc.

Enumerate the principal physical properties of water. Describe an experiment showing the diffusive power of hydrogen.

What is meant by the occlusion of hydrogen? What metallic substance possesses the greatest power of occluding hydrogen?

What is the probable source of the free hydrogen found in meteorites?

Describe the principal chemical properties of hydrogen. Describe an experiment illustrating any one of these properties.

How may it be shown experimentally that water is the sole product of the combustion of hydrogen in air?

Name the principal natural sources of chlorine.

How may free chlorine be conveniently prepared?

Define simple displacement as applied to the collection of a gas.

Enumerate the physical properties of chlorine. What are its characteristic chemical properties?

Why does chlorine exhibit its bleaching properties best in the presence of moisture?

How is hydrochloric acid most conveniently prepared? Write its chemical formula. Describe its properties.

Of what does commercial hydrochloric acid consist?

Describe a simple test for the presence of an acid substance. What is the use of litmus paper?

What are the principal natural sources of bromine?

Describe the principal physical properties of bromine. From what circumstance does bromine derive its name?

Describe any experiment with bromine.

What is the compound of bromine and hydrogen called?

What is the principal source of the iodine of commerce?

Describe the method employed for the preparation of iodine.

Give the principal properties of iodine. How is the tincture of iodine prepared? Describe the test generally employed for iodine.

Name the principal source of fluorine.

Why has fluorine never been isolated?

Describe the method by which hydrofluoric acid is generally prepared. What properties does this substance possess?

Describe the method generally adopted for etching glass by hydrofluoric acid. Describe the sand-blast process for etching glass.

SECTION II.

OXYGEN, SULPHUR, SELENIUM, AND TELLURIUM.

CHAPTER III.

OXYGEN AND ITS COMPOUNDS WITH THE PRECEDING ELEMENTS.

OXYGEN.

O = 16. Density = 16. Compared with hydrogen = 1.1056. Molecular weight = 32. Quantivalence = II. Free molecule, $O=O$. Discovered by Priestley in 1774.

84. Occurrence in Nature.—Of all elementary substances, none are so widely diffused, or occur in as large quantities, as oxygen. This element occurs in nature both free and combined. It exists free in the atmosphere, one-fifth of the volume of which is pure oxygen. In combination, it forms very nearly one-half by weight of the known crust of the earth. It is the principal ingredient in water, which is composed of eight-ninths by weight of pure oxygen. It also forms a large part of all plants and animals.

The name oxygen (from ὀξύς, acid, and γεννάω, I produce) was applied to this element because it was originally believed that oxygen was the great producer of acids. As we have already seen, this view is incorrect, acids being substitution compounds formed by the combination of an electro-negative substance with hydroxyl.

Though the amount of free oxygen on the earth is very great, yet it is far exceeded by the amount in combination. The energetic affinity of oxygen for the other elements naturally tends to decrease the amount of the free element.

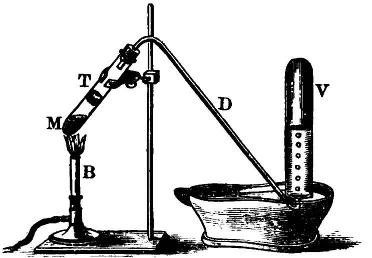


Fig. 63.—Preparation of Oxygen.

85. Preparation of Oxygen.—Oxygen may be prepared in a variety of ways. That adopted by its discoverer, was by the decomposition of mercuric oxide by heat. The mercuric oxide, M, Fig. 63, is placed in a *test-tube*, T, and is decomposed by the heat of a Bunsen burner, B. A delivery-tube, D, serves to convey the gas to the vessel, V, placed in a pneumatic trough.

A *test-tube* is a tube of thin glass closed at one end. It can be heated without fracture, and is suitable for testing small quantities of any common substance.

A Bunsen burner, an instrument much used in the laboratory as a convenient source of heat, is a burner arranged so as to mix air with ordinary illuminating gas before burning it. When lighted, the gas burns with a pale-blue flame, much hotter than the ordinary gas-flame.

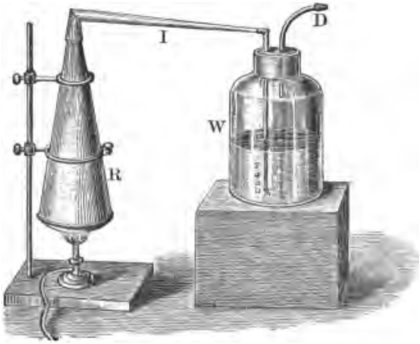


Fig. 64.—Preparation of Oxygen by Decomposition of Potassium Chlorate.

Where large quantities of oxygen are required, as for experimental purposes, it is more cheaply obtained by the decomposition of potassium chlorate by heat.

The potassium chlorate is coarsely ground and placed in a sheet-iron retort, R, Fig. 64, to which is luted (made gas-tight with moistened clay) an iron pipe, I, bent as shown. Before passing through D to the pneumatic trough, the gas is washed by passing through a wash-bottle, W.

It has been found in practice that a little manganese dioxide, mixed with the chlorate, facilitates the evolution of the gas. The action of this substance, though perhaps not exactly understood, is most probably due to the formation and subsequent decomposition of a higher oxide of manganese.

The retort is heated by a furnace or a Bunsen burner. Towards the last a high heat is required to decompose all the chlorate.

The reaction may be expressed as follows, viz.:

$$KClO_3 \text{ (Heated)} = KCl + O_3.$$

Potassium Chlorate = Potassium Chloride + Oxygen.

86. Physical Properties.—Oxygen is a colorless, transparent, tasteless, and inodorous gas. It is slightly soluble in water; all water, when exposed to the air, dissolves the gaseous constituents of the atmosphere to a slight extent.

By the combined influence of great pressure and cold, oxygen is liquefied. Liquid oxygen resembles water, and has nearly the same specific gravity.

87. Chemical Properties.—Oxygen possesses very energetic chemical affinities, combining with nearly every other chemical element. It is the great supporter of combustion, all ordinary combustion consisting in the combination of oxygen with the hydrogen and carbon of the combustible body. Oxygen is a neutral body; that is, it possesses neither acid nor basic properties.

The ability of oxygen to support combustion is strikingly manifested by igniting combustible substances in jars filled with the pure gas. Under such circumstances a very energetic or rapid combustion ensues.

Experiment 18.—Plunge a lighted taper into a small jar filled with oxygen, and notice how much more rapidly and brightly it burns than in common air.

Experiment 19.—Allow a candle or taper to burn quietly in air for some time until it has a long wick. Now blow out the flame, and, while the wick is still glowing, plunge it in a small jar of oxygen, when it will be instantly relighted. It may then be withdrawn from the jar, blown out, and relighted a number of times.

The property possessed by pure oxygen of inflaming a glowing taper is often utilized, in the preparation of oxygen, to test the purity of the gas. The first portions of gas that escape from the retort being mixed with air are rejected, and the gas is not collected until the issuing stream will relight the glowing taper.

Experiment 20.—Ignite a small quantity of sulphur in a *deflagrating spoon* (a small metallic cup connected with a wire), and immerse it in a jar of oxygen. A rapid combustion ensues, with the emission of a curious blue light. The sulphur burns into sulphurous oxide, a gaseous compound of sulphur and oxygen.

Experiment 21.—Ignite a small piece of phosphorus in a deflagrating spoon, and immerse in a jar of pure oxygen. A dazzling combustion ensues, and the jar becomes filled with dense white fumes. The phosphorus burns into phosphoric oxide, a solid compound of phosphorus and oxygen.

Experiment 22.—Take a watch-spring, Fig. 65, twisted spirally, so as to obtain a greater length, and, wrapping a small piece of cotton thread on the end, dip it in melted wax, and ignite. If it be now plunged in a jar of oxygen, O, the heat of the burning wax will ignite the wire, which will burn with great brilliancy, throwing out bright sparks, and becoming converted into oxide of iron.

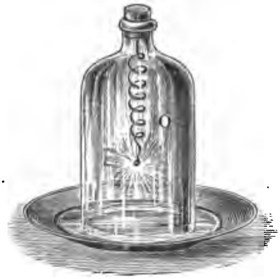


Fig. 65.
Combustion of Iron in Oxygen.

88. Slow Combustion.—In striking contrast with the preceding instances of rapid combustion, are the more gradual combinations of oxygen, or, as they are generally called, oxidations. Thus the rusting of iron is a true combustion of the iron by the oxygen of the air.

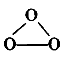
Foul organic matters, thrown into water, render it unfit for drinking purposes. If, however, the water be sufficiently exposed to the air, as in a shallow stream, the oxygen dissolved in the water gradually oxidizes the organic impurities, and thus purifies the water. Authorities are divided as to the distance in which a river will purify its water in this manner. Probably from five to seven miles will suffice, if the river be shallow, and the organic matter not too great in amount. The decay of animal and vegetable substances is a species of gradual combustion.

89. Action of Oxygen in Respiration.—All bodily exertion results in the death of a part of the body. These dead parts of the body are thrown off from it in a variety of ways. Much, however, pass into the blood, and change it from bright red arterial blood, to dark, impure venous blood. It is the province of the inspired (breathed-in) oxygen to burn out these impurities by means of a gradual combustion, thus purifying it and restoring its bright red color. The expired (breathed-out) air containing, among other substances, carbonic acid gas and vapor of water, resulting, partly, from these combustions. All animals require air in order to exist, and all are furnished with special organs for breathing it.

90. Ozone.—The peculiar smell noticeable when a series of electric sparks are passed through dry air, is due to a modification of oxygen called ozone. It may also be obtained by the gradual oxidation of a piece of phosphorus placed in a bottle and partially covered with water. If a piece of moistened paper, impregnated with starch and potassium iodide, be exposed to ozone, it is blued by the iodine which is liberated from the iodide by the ozone.

Ozone possesses very energetic oxidizing powers, readily oxidizing silver, and oxidizing and destroying numerous organic substances. At about 550° F. it is converted into ordinary oxygen, which, occupying a greater bulk than that occupied by the ozone, proves that ozone is simply condensed oxygen.

It is believed that ozone is triatomic oxygen, three atoms of oxygen being condensed into two volumes. Its molecular structure is as shown in the annexed formula.



Water.

$H_2O = 18$. Vapor density compared with $H = 9$. Compared with air $= 0.623$. Composition determined by Lavoisier in 1783.

91. Occurrences in Nature.—Water is universally distributed throughout nature. As the ocean, it covers two and seven-ninth times more of the earth's surface than the land. It is distributed as vapor through the atmosphere, from whence it is condensed as rain, hail, snow, fog, cloud, mist, or dew. It forms the principal food of all animals and plants, and is therefore of immense importance in the economy of nature.

92. Composition of Water.—As we have already seen, water is the sole product of the combustion of hydrogen in oxygen.

The exact composition of water is best ascertained by synthesis. A tube open at one end, is partly filled with a gaseous mixture containing two volumes of hydrogen and one volume of oxygen, and placed upright in a vessel of mercury. If an electric spark be passed through the gases, they combine with a flash, and the mercury rises and fills all the tube, except the space occupied by the small quantity of water formed. If, now, the tube be surrounded by a longer tube filled with boiling water, the water in the mercury tube is converted into vapor, which, proper allowance being made for the temperature, occupies the exact volume of the hydrogen introduced. The two volumes of hydrogen and the one volume of oxygen have been condensed to form two volumes of water vapor.

93. Physical Properties of Water.—Water possesses a number of physical properties that enable it to fulfil the important part it plays in the economy of nature.

Pure water is a transparent, inodorous, and tasteless liquid that freezes at 32° F., boils at 212° F., and evaporates or passes into vapor at all temperatures. Though colorless in small bulk, it appears of a deep blue when in great bulk, as in the ocean or in deep lakes. It is but slightly compressible, and is a bad conductor of heat and electricity.

Water expands when heated and contracts when cooled. It acquires its maximum (greatest) density from loss of heat at the temperature of 39°.2 F. When at this temperature it expands whether heated or cooled.

Water takes in more heat on being warmed, and gives out more heat on being cooled, than any other common substance. When ice melts, or water evaporates, a large quantity of heat disappears or is rendered latent, all, however, reappearing when the water freezes, or the vapor condenses. Large bodies of water, therefore, tend to render the climate of a country more uniform than it would otherwise be.

Ice is frozen or crystallized water. In the snow-flake these crystals are grouped in numerous star-like forms, shown in Fig. 66. They can readily be examined by allowing the flakes to fall on a piece of dark cloth.

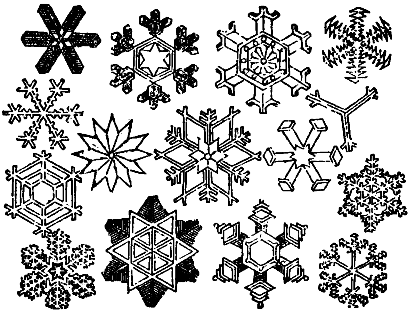


Fig. 66.—Snow Crystals.

Water possesses very great solvent powers, dissolving many solids, liquids, and gases. All water exposed to the atmosphere absorbs its constituent gases; it is these gases that impart to ordinary drinking water its agreeable taste. During its flow over the ground, or through the rocky strata of the earth's crust, the water dissolves various mineral matters from the earth; therefore, all river, well, and especially spring water, contain dissolved mineral matters. The waters from certain springs contain so large an amount of these mineral substances as to receive the name of mineral waters. Such springs generally owe their larger percentage of mineral matters to their increased solvent powers, due either to the carbonic acid gas dissolved in them, or to their higher temperature.

Various names are given to mineral waters, taken either from the locality of the springs, or from their principal mineral constituent; thus, waters containing lime are called *calcareous;* those containing sulphur, sulphuretted hydrogen, or other sulphur salts, are called *sulphurous*; those containing iron are called *chalybeate;* those containing common salt are called *brines;* those containing carbonic acid are called *acidulous.*

When river, well, or spring water is used in steam-boilers, only the pure water passes off as vapor; the mineral ingredients remain in the boiler and form a hard mineral coating called a *scale.*

Water may be freed from impurities mechanically suspended in it by filtering through any porous material, charcoal being preferable for this purpose. It may be freed from dissolved impurities by *distillation;* that is, the water is evaporated by heat, and the vapor condensed in a cooled receiver.

94. Chemical Properties of Water.—Pure water is a neutral body; that is, possesses neither acid nor basic properties. As we have already seen, however, it forms both acids and bases by the replacement of one of its hydrogen atoms by electro-negative, or electro-positive radicals respectively. These bodies are called *hydrates,* the former being termed *acid hydrates,* and the latter, *basic hydrates.* A hydrate may be univalent, bivalent, trivalent, quadrivalent, etc., according to the number of its replaceable hydrogen atoms, the acids being termed *mono-, di-,* or *tri-basic,* and the bases *mono-, di-,* or *tri-acid.*

A positive element, therefore, decomposes water with the evolution of hydrogen, as in the case of the metals potassium and sodium; this decomposition is shown as follows, viz.:

$$\underset{\text{Water}}{2H_2O} + \underset{\text{Potassium}}{K_2} = \underset{\text{Potassium Hydrate}}{2KOH} + \underset{\text{Hydrogen.}}{H_2}$$

Or the potassium hydrate may lose its hydrogen, thus:

$$\underset{\text{Potassium Hydrate}}{2KOH} + \underset{\text{Potassium}}{K_2} = \underset{\text{Potassium Oxide}}{2K_2O} + \underset{\text{Hydrogen.}}{H_2}$$

A negative element may liberate oxygen by combining with both the hydrogen atoms.

Water combines directly with many salts, and in such cases generally causes them to assume the crystalline state. The water in this condition is termed *water of crystallization.* Under these circumstances the oxygen possibly acts as a tetrad. Common alum contains twenty-four molecules of water combined in this manner.

Some crystals, such as those of common washing soda, lose their water of crystallization when exposed to the air, and become covered with a white powder; they are then said to *effloresce.* Others, such as calcium chloride, exposed to the air, attract its moisture, and melt; they are then said to *deliquesce.*

95. The Oxyhydrogen Blow-pipe.—A stream of hydrogen burning in an atmosphere of pure oxygen, forms a source of artificial heat so intense that even refractory (difficultly fusible) metals, like platinum, melt therein as readily as wax does in the flame of a candle; iron burns in this flame with brilliant scintillations.

An arrangement for readily obtaining this flame is known as the *oxyhydrogen,* or *compound blow-pipe,* and is shown in Fig. 67. The hydrogen is applied through the nozzle at H, Fig. 67; the oxygen through that at O. The hydrogen is first turned on and lighted, and the oxygen then gently turned on; the flame is of a faint bluish tint, and is almost invisible; if,

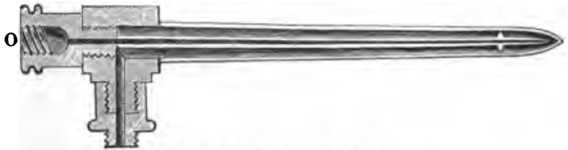


Fig. 67.—Oxyhydrogen Blow-pipe.

however, a refractory body, such as a piece of lime, be held therein, it becomes heated to a dazzling incandescence, and forms the well-known *lime-light.*

Caution is necessary, in the use of the compound blow-pipe, to avoid a dangerous explosion due to the mixture of the gases.

The Atmosphere.

96. Composition of the Atmosphere.—The atmosphere consists of a mechanical mixture of oxygen and nitrogen, together with a small quantity of carbonic acid and vapor of water. It contains about seventy-seven parts by weight of nitrogen to twenty-three parts of oxygen. The carbonic acid, which is very nearly constant, varies from four to six parts in every 10,000. This proportion is not far from one cubic inch of carbonic acid to every cubic foot of air. The vapor of water varies largely in amount. It is never entirely absent.

In the neighborhood of large cities the percentage of carbonic acid increases slightly, and various organic and inorganic impurities occur.

The quantity of moisture in the air at any time can be determined by the use of an instrument called a *hygrometer.* It may also be determined by passing a known quantity of air through a number of calcium-chloride tubes, and noting their increase in weight.

97. Uses of the Different Ingredients of the Atmosphere.—The oxygen of the atmosphere is the sole ingredient necessary for the respiration of animals. It is also the sole supporter of ordinary combustion.

The principal use of the nitrogen of the atmosphere appears to be that of a dilutant. Were the air composed of pure oxygen, combustion would act so energetically that, once started, it would scarcely end while any oxidizable substance remained unoxidized. Life, too, as at present organized, would even disappear on account of the intensity of the vital functions.

The carbonic acid is necessary for the existence of plant life. The leaves of the plants absorb the carbonic acid from the atmosphere. Under the influence of the sunlight, the carbonic acid is decomposed, the carbon retained for the formation of vegetable tissue, and the oxygen expelled.

The constancy of the composition of the atmosphere is maintained by the opposite actions of animals and plants—the animals giving out carbonic acid in the place of the oxygen they absorb, and the plants giving out oxygen in the place of the carbonic acid they absorb.

That carbonic acid is in reality expelled by animals may be shown by the following:

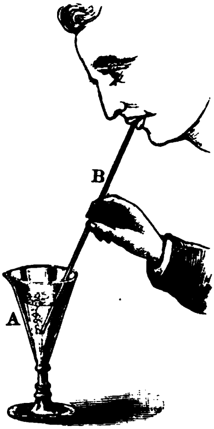


Fig. 68.—Detection of Carbonic Acid in the Breath.

Experiment 23.—Blow the breath through a tube, B, Fig. 68, and allow it to bubble through lime-water contained in the glass, A. The water will soon be observed to lose its clearness, and to become turgid by the formation of calcium carbonate, from the carbonic acid of the breath combining with the calcium in the lime-water.

The aqueous vapor of the atmosphere is necessary for the continued existence of both animals and plants, since it forms their principal food. All vegetable and animal substances contain in their composition very large quantities of water. In fact, water forms their chief ingredient. The continued absence of water in any section of country causes it to become a desert.

98. Uses of the Atmosphere as a Whole.—The atmosphere retains and moderates the solar heat. Had the earth no atmosphere, it would be subjected to very marked changes of temperature, growing intensely hot on the rising of the sun, and bitterly cold on its setting. Protected by the atmosphere, the sun's rays experience difficulty both in entering and leaving the gaseous envelope.

The aqueous vapor, together with the air through which it is diffused, serves as an excellent vehicle to convey the excess of heat in the tropical regions to the polar regions. The heat at the equator is largely rendered latent in evaporating the water areas; carried by the winds to other regions, this heat again becomes sensible, when the vapor is precipitated as rain, hail, snow, dew, mist, fog, or cloud. Winds are currents in the atmosphere, caused by differences of temperature.

◆

Compounds of Oxygen with Chlorine, Bromine, and Iodine.

99. Compounds of Oxygen and Chlorine.—Chlorine and oxygen unite to form a series of compounds called oxides; these may be either *anhydrous* (not containing water) or *hydrated* (containing water). The compounds of oxygen and chlorine are generally *unstable* and explosive. They are as follows, viz.:

Anhydrous Oxides.	Hydrated Oxides.
Cl_2O = Hypochlorous oxide.	$HClO$ = Hypochlorous acid.
Cl_2O_3 = Chlorous oxide.	$HClO_2$ = Chlorous acid.
Cl_2O_4 = Chlorine peroxide.	$HClO_3$ = Chloric acid.
	$HClO_4$ = Perchloric acid.

Hypochlorous oxide possesses powerful bleaching properties. It is a brown-red liquid, with a very low boiling-point. It is exceedingly unstable, and often decomposes explosively.

Chlorous oxide is an unstable, greenish gas, readily soluble in water, to which it imparts a deep, golden-yellow color.

Chlorine peroxide is a highly dangerous, and often spontaneously explosive gas, of a yellow color, and aromatic odor.

Hypochlorous acid is a dark, yellow liquid possessing powerful bleaching properties. The bleaching salt, incorrectly called chloride of lime, owes its powerful bleaching properties to the liberation of hypochlorous acid, and the decomposition of the latter, which yields free chlorine.

Chloric acid forms an important group of salts called *chlorates.* **Chloric acid** is a syrupy liquid of a golden-yellow color, possessing very energetic oxidizing properties.

100. Compounds of Oxygen with Bromine and Iodine.— Bromine combines with oxygen to form the following hydrated compounds, viz.:

$HBrO$ = Hypobromous acid.
$HBrO_3$ = Bromic acid.
$HBrO_4$ = Perbromic acid.

These compounds are similar in their composition to the corresponding chlorine compounds, and possess somewhat similar properties. They are, however, more stable than the chlorine compounds.

Hypobromous acid is a liquid of a light, yellow color, and closely resembles hypochlorous acid in its properties, being, like it, a powerful bleacher.

Bromic acid somewhat resembles chloric acid. Its salts are called bromates.

Iodine combines with oxygen and forms two compounds, viz.: I_2O_5 = Iodic oxide, and I_2O_7 = Periodic oxide. When hydrated, these oxides form the corresponding acids. None of these compounds are very important.

* * *

SYLLABUS.

None of the elementary substances are so widely diffused in nature, or exist in so large a quantity, as oxygen.

Oxygen forms nearly one-half by weight of the earth's crust, eight-ninths by weight of water, and about one-fifth by volume of the atmosphere.

Oxygen may be conveniently prepared by the decomposition by heat of either mercuric oxide or potassium chlorate.

Oxygen is a colorless, transparent, tasteless, and inodorous gas that is slightly soluble in water. It possesses very energetic chemical affinities, and combines with nearly all the elementary substances.

Oxygen is the supporter of all ordinary combustion. It is necessary for the respiration of animals.

Pure oxygen is a neutral substance; that is, it possesses neither acid nor basic properties.

All combustible substances burn very energetically in pure oxygen.

Oxygen is necessary for respiration, because it is needed to oxidize or burn the impurities in the blood, so as to change the impure, dark, venous blood into pure, bright red arterial blood.

Ozone is the name given to a modification of oxygen formed by passing electric sparks through dry air, or by the gradual oxidation of phosphorus. It is tri-atomic oxygen condensed into two volumes.

Water is the sole product of the combustion of hydrogen in oxygen.

If a mixture containing two volumes of hydrogen and one of oxygen be united by an electric spark, they will completely combine and form water vapor. The volume occupied by this vapor at 212° F. is exactly equal to that of the hydrogen, consequently two volumes of hydrogen and one volume of oxygen have been condensed into two volumes of water vapor.

Pure water is a transparent, tasteless, colorless, and inodorous liquid that freezes at 32° F. and boils at 212° F. In large bulk it has a deep blue color.

Water acquires its maximum density, by loss of heat, at the temperature of 39°.2 F.

Water has a high specific heat; that is, takes in more heat on being heated, and gives out more on cooling, than any common substance. Large bodies of water, therefore, moderate the extremes of natural climate.

Ice is frozen or crystallized water. The ice crystals are arranged in the snow-flake in beautiful star-like forms.

Water possesses very great solvent powers. All river, well, or spring water contains various mineral substances in solution, derived from the strata over which the water has flowed.

Calcareous waters contain lime in solution; sulphurous waters contain sulphur or some of its compounds; chalybeate waters contain iron; brines contain common salt; acidulous waters contain carbonic acid gas.

Water is a neutral body; by the replacement of its hydrogen atoms, however, it forms both acids and bases. These compounds are called hydrates. The quantivalence of basic hydrates may be univalent, bivalent, trivalent, etc. Acid hydrates are mono-basic, di-basic, or tri-basic.

Water combines directly with many crystallizable salts as water of crystallization. Some salts lose this water, or effloresce, when exposed to the air; others abstract water from the air and melt, or deliquesce.

The oxyhydrogen blow-pipe flame consists of a stream of hydrogen burning in pure oxygen. It affords a very intense source of heat.

The atmosphere consists of a mechanical mixture of oxygen, nitrogen, carbonic acid, and the vapor of water.

We can determine the amount of aqueous vapor in the air by means of a hygrometer, or by passing the air through tubes containing calcium chloride.

The oxygen of the air supports combustion and respiration. The nitrogen acts as a dilutant. The carbonic acid gives carbon to plants for their woody fibre.

Plants take in carbonic acid and give out oxygen. Animals take in oxygen and give out carbonic acid. In this way the constancy of the composition of the atmosphere is maintained.

The aqueous vapor of the atmosphere is necessary to the existence of both plants and animals, because it forms their chief food.

The atmosphere covers the entire earth with a gaseous envelope that prevents the sun's heat from either entering or leaving it very readily.

Chlorine and oxygen unite to form a number of oxides and acids. These compounds are very unstable, and often explosive. Hypochlorous acid and chloric acid are the most important.

The compounds of oxygen with bromine and iodine are not very important.

QUESTIONS FOR REVIEW.

Name the principal natural sources of oxygen. In what different ways may oxygen be prepared? Which of these is preferable when large quantities of the gas are required?

What is the use of a test-tube? Of a Bunsen burner?

Give the principal physical properties of oxygen. Name some of its most important chemical properties.

What simple means may be employed to test the purity of oxygen gas?

Explain the manner in which running water, exposed to the air, may be purified, or freed from putrefying organic impurities.

Explain the action of oxygen in respiration.

What is ozone? How is it formed? Describe its properties. By what simple test may its presence be detected?

Describe any method employed for showing the composition of water by synthesis.

Enumerate the more important physical properties of water.

At what temperature does water acquire its maximum or greatest density?

Why should large bodies of water moderate the extremes of natural climate?

State any facts that prove the high solvent powers of water. Define calcareous, sulphurous, chalybeate, and acidulous waters.

How may water be purified or freed from foreign matters mechanically suspended in it? How may it be freed from foreign matters dissolved in it?

Describe some of the more important chemical properties of water.

What is meant by water of crystallization?

When is a salt said to deliquesce? When is it said to effloresce?

Describe the construction of the compound blow-pipe. How is the lime-light obtained?

Name the gaseous ingredients of the atmosphere. State briefly the use of each of these ingredients.

How may the presence of carbonic acid in the breath be shown experimentally?

Describe some of the uses of the atmosphere acting as a whole.

Name some of the more important compounds of oxygen and chlorine. What general properties do all these substances possess?

To which of these substances does the bleaching powder known as chloride of lime owe its bleaching properties?

Name some of the compounds of oxygen with bromine and iodine.

CHAPTER IV.

SULPHUR, SELENIUM, AND TELLURIUM.

SULPHUR.

S = 32. Density of vapor = 32. Compared with air = 2.22. Molecular weight = 64. Quantivalence = II., IV., VI. Free molecule, S=S. Specific gravity of solid = 2.05. Melting-point = 114.5° F.

101. Occurrence in Nature.—Sulphur occurs in nature in the free or native state. This fact, together with its striking color, has caused it to be known from the earliest times. The name brimstone (*brennes-stone,* the stone that burns) was originally given to it. Sulphur, compounded with various other elements, is very widely diffused in nature, both in the mineral kingdom, as sulphates and sulphides, and also in the animal and vegetable worlds. The principal sources of most of the sulphur of commerce, are the volcanic districts of Italy.

102. Preparation—Refining Sulphur.—Native sulphur is generally found mixed with various earthy matters. It is freed from these by a simple process of distillation; the crude sulphur thus obtained is *refined,* or made purer, by a second distillation.

The apparatus employed is shown in Fig. 69. Melted sulphur contained in the vessel, C, is allowed, at suitable intervals, to flow into a cast-iron cylinder, A, placed above a furnace, F. A large chamber, B, of masonry receives the sulphur vapor, which either condenses on its walls in the form of *flowers of sulphur,* or, when the walls are too hot, condenses, and, collecting on the inclined bottom of the chamber, is run off at suitable intervals and moulded, generally in cylinders, thus forming *roll sulphur.*

Sulphur is extensively used in the arts in the manufacture of matches, gunpowder, and oil of vitriol.

103. Physical Properties of Sulphur.—Pure sulphur is a tasteless, inodorous, and nearly opaque, brittle solid of a lemon-yellow color. It conducts heat very poorly; when a roll of sulphur is held in the hand, a peculiar crackling sound is heard, due to local expansions. It is a non-conductor of electricity, and becomes electrified by friction. When melted, it becomes a yellow liquid lighter than the unmelted sulphur.

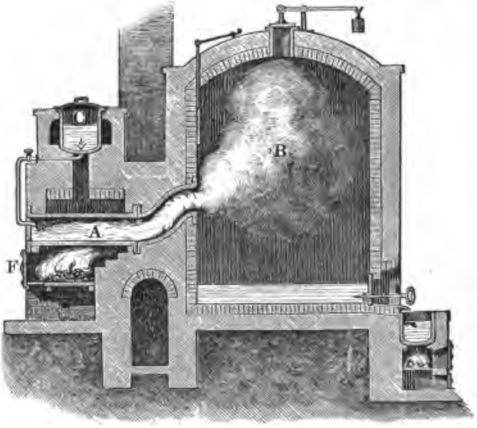


Fig. 69.—Refining Sulphur.

104. Modifications of Sulphur.—At 824° F., sulphur boils and yields a red vapor. Sulphur is insoluble in water, but is soluble in carbon disulphide. If melted sulphur is allowed to cool on the surface so as to form a crust, and the remaining liquid poured off through an opening in the crust, the interior becomes filled with flexible needle-shaped crystals, of brownish yellow, transparent sulphur. They soon, however, lose their transparency and flexibility.

Sulphur crystallizes in two distinct crystalline systems, that is, it is *dimorphous*. The natural crystals occur as modified octahedra, as seen in Fig. 70. When sulphur is dissolved in carbon disulphide, the solution yields, on spontaneous evaporation, that is, evaporation unaided by artificial heat, crystals of this form. It also occurs in the form of oblique rhombic prisms. This is the form in which sulphur crystallizes by fusion.

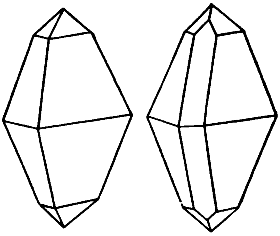


Fig. 70.—Crystals of Sulphur.

The crystallographic modifications of sulphur are very numerous. As many as thirty have been found.

A peculiar condition of sulphur is obtained by gradually raising the temperature of melted sulphur, when it is changed into a thick brown-red liquid. If, now, it be poured into cold water, it becomes a soft, transparent, elastic, brownish yellow, amorphous mass. After several days, however, it acquires the properties of ordinary sulphur. Sulphur, therefore, like oxygen, occurs in more than one condition or modification.

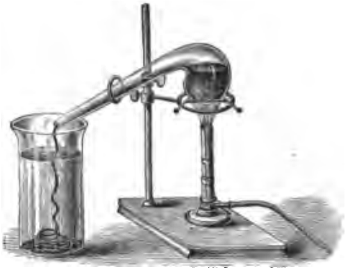


Fig. 71.—Amorphous Sulphur.

An allotropic modification of a substance is one in which, without changing its chemical composition, it can assume a condition which has physical and chemical properties distinct from those it ordinarily possesses.

These three allotropic modifications of sulphur are sometimes indicated by the Greek letters α, β, γ. Thus:

$(S\alpha)$ = the octahedral variety;
$(S\beta)$ = the oblique rhombic variety;
$(S\gamma)$ = the amorphous variety.

105. Changes Observed during Liquefaction.—Liquid sulphur undergoes curious changes as it gradually acquires a higher temperature. When first melted, it is a transparent, mobile liquid. At about 400° F. it becomes almost black, and thickens so that it can only be poured with difficulty; at about 500° F. it again becomes mobile, and remains so until it finally boils.

106. Chemical Properties of Sulphur.—Sulphur possesses energetic chemical affinities, combining directly with many other elements. On being sufficiently heated, it combines directly with oxygen, burning with a pale-blue flame, and producing a characteristic, pungent odor.

Experiment 24.—Connect a large flask, with a small retort, in which some sulphur is placed. On heating with a Bunsen burner, the vapor passes into the larger flask, and condenses on its cool walls in the form of flowers of sulphur. In order to aid this condensation, it is necessary to keep the flask cool by allowing a stream of water to play upon it.

Experiment 25.—Heat a small quantity of sulphur in a test-tube, and, when the vapor is freely given off, drop into the tube some pieces of copper turnings or copper foil, previously slightly heated. They will be observed to glow brilliantly, until completely converted into copper sulphide. This is a case of true combustion.

◆

Hydrogen Sulphide.

$H_2S = 34$. Density $= 17$. Compared with air $= 1.192$. Molecular structure, H—S—H. Discovered by Meyer and Rouelle in 1777.

107. Occurrence in Nature and Preparation. — Hydrogen sulphide, or sulphuretted hydrogen, occurs naturally in the gases from certain volcanic districts, and in solution, in the waters of certain sulphur springs. It is to this gas that these waters owe their medicinal properties and their offensive smell. The characteristic smell of rotten eggs is also due to the formation of this gas. Decaying organic matter generally evolves hydrogen sulphide.

Hydrogen sulphide is most conveniently prepared by the action of dilute sulphuric acid on ferrous sulphide.

The ferrous sulphide is placed in the bottle, B, Fig. 72, and dilute acid poured in through the safety-tube, S. The evolved gas is forced through the wash-bottle, W, to free it from acid fumes and other impurities. To permit the ready separation of the generating-bottle from the wash-bottle, the delivery-tube from the generating-bottle passes through a larger tube tightly fitted to one of the necks of the wash-bottle, and passing down below the water surface.

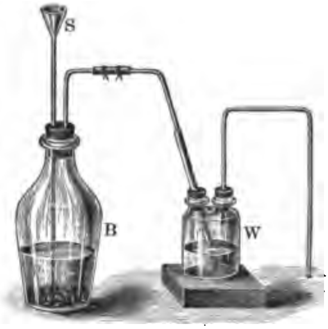


Fig. 72.
Preparation of Hydrogen Sulphide.

108. Properties of Hydrogen Sulphide.—Hydrogen sulphide is a colorless gas, having a sweetish taste, but an extremely disagreeable and penetrating odor. It is a poisonous gas even when diluted with air, but may impart its characteristic odor to the air of a room when in too small quantities to be harmful. By pressure, the gas is converted into a transparent liquid slightly lighter than water. The gas burns in air with a bluish flame, producing water and sulphurous oxide, and, when mixed in suitable proportions with oxygen, burns explosively. It is feebly acid, slightly reddening blue litmus. The haloids decompose this substance, on account of their superior affinity for hydrogen.

Hydrogen sulphide is very extensively employed in the laboratory for detecting the presence of a number of metallic bodies, with which it forms characteristic precipitates; that is, substances which are insoluble in the liquid in which they are formed, and which are consequently precipitated to the bottom or rise to the surface of the liquid, according to their specific gravity. These precipitates are sulphides. By the addition of hydrogen sulphide, for example, to copper sulphate, we obtain a brown-red cupric sulphide, thus:

$$CuSO_4 + H_2S = CuS + H_2SO_4$$

Copper Sulphate + Hydrogen Sulphide = Cupric Sulphide + Sulphuric Acid.

Experiment 26.—Pass sulphuretted hydrogen gas through separate solutions of manganese, lead, and arsenic, in tall precipitating jars, that is, cylindrical jars suitable for showing the characteristic appearance of precipitates. Characteristic flesh-colored, black, and yellow precipitates will be formed respectively.

109. Compounds of Sulphur and Oxygen.—Sulphur combines with oxygen and forms a number of oxides; the most important are SO_2 *sulphurous oxide,* and SO_3 *sulphuric oxide.* Combined with one molecule of water, they form the corresponding acids, thus: H_2SO_3 = sulphurous acid, and H_2SO_4 = sulphuric acid.

* * *

Sulphurous Oxide.

$SO_2 = 64$. Density = 32. Compared with air = 2.234.

110. Preparation.—Sulphurous oxide, or sulphurous acid gas, is produced when sulphur is burned in air. It is, however, more conveniently prepared by decomposing sulphuric acid by metallic copper, with the aid of heat. The reaction may be represented as follows, viz.,

$$Cu + 2H_2SO_4 = CuSO_4 + 2H_2O + SO_2$$

Copper + Sulphuric Acid = Copper Sulphate + Water + Sulphurous Oxide.

Sulphurous oxide gas must either be collected over mercury, or by simple displacement, as it is soluble in water.

A solution of sulphurous oxide in water is often used in the laboratory as a reagent. It is readily prepared by passing the gas through water contained in a number of wash-bottles. It becomes gradually oxidized, however, and converted into sulphuric acid.

111. Physical Properties of Sulphurous Oxide.—Sulphurous oxide is a colorless gas, having the well-known suffocating odor of burning sulphur. Its great density permits it to be collected by simple displacement, but if required pure, it must be collected over mercury. Sulphurous oxide is converted by cold or pressure into a colorless liquid. Fig. 73 shows apparatus suitable for the preparation of liquid sulphurous oxide. The Florence flask, O, contains metallic copper and sulphuric acid. The evolved gas is purified by passing through a wash-bottle, B, from which it passes through a spiral glass tube, C, surrounded by a freezing mixture, D, which condenses it. The condensed liquid is collected in a receiver, E, also surrounded by a freezing mixture.

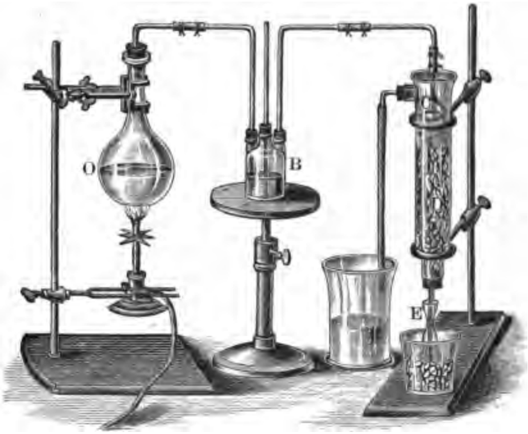


Fig. 73.—Preparation of Liquid Sulphurous Oxide.

If liquid sulphurous oxide be exposed to the air, it evaporates so rapidly that its temperature is reduced far below zero. It is, therefore, employed for readily obtaining low temperatures. The operation of several ice-machines is based on the rapid evaporation of liquid sulphurous oxide.

112. Chemical Properties of Sulphurous Oxide.—Sulphurous oxide does not support ordinary combustion. A lighted taper plunged into a jar of the gas is instantly extinguished. Some metals, however, as potassium, ignite spontaneously when thrown into the gas.

Sulphurous oxide possesses a strong acid taste, and readily reddens litmus paper. It has a powerful affinity for oxygen, thus enabling it to deoxidize a number of bodies. In the presence of moisture, it possesses powerful bleaching properties, and is much employed for the bleaching of straw, silk, wool, and other fabrics that are destroyed by chlorine.

Sulphurous oxide owes its bleaching power to its ability to take the oxygen from the water to form sulphuric acid, thus liberating the H_2, which is the true bleacher. The reaction is as follows, viz.,

$$\underset{\text{Sulphurous Oxide}}{SO_2} + \underset{\text{Water}}{2H_2O} = \underset{\text{Sulphuric Acid}}{H_2SO_4} + \underset{\text{Hydrogen.}}{H_2}$$

113. Phenomena of the Nascent State.—We have already explained, in speaking of the bleaching-power of chlorine, that it manifests this property in the presence of water, the chlorine taking the hydrogen and liberating *free oxygen*, which acts as the bleacher. In the case of sulphurous oxide, we have seen that it is *free hydrogen* that acts as the bleacher. Now, neither oxygen nor hydrogen, that have been liberated for any time, possess such properties. It is evident, therefore, that a substance just evolved from combination may possess properties quite different from those it afterwards possesses. This state has been called the *nascent state* (*nascor*, to be born).

The peculiar properties possessed by an element in the nascent state are due to the fact that the element is then in the free or atomic condition, with its bonds open. Its affinities must then, necessarily, be more energetic than those it possesses when it assumes the condition of a saturated atom or molecule.

114. Sulphuric Oxide.—Sulphuric oxide, or sulphuric anhydride, is a white, fibrous, silky powder, formed by gently heating fuming sulphuric acid in a retort, and collecting the vapor in a receiver surrounded by a freezing mixture. It possesses such a powerful affinity for water that it produces a hissing sound when thrown into it, and forms sulphuric acid. Thus,

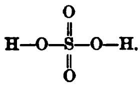
$$SO_3 + H_2O = H_2SO_4$$

Sulphuric Oxide + Water = Sulphuric Acid.

Experiment 27.—Fill a bell jar with the fumes of sulphurous oxide by placing therein a small quantity of burning sulphur. Now expose some fresh flowers to the acid fumes, and they will soon be bleached. A red rose, for example, becomes whitened. By dipping the rose in dilute sulphuric acid its red color will be restored.

Experiment 28.—Into a large jar, filled with water deeply colored with potassium permanganate, pour a few drops of sulphurous oxide dissolved in water; the solution will at once lose all its color.

Sulphuric Acid.



H_2SO_4 = 98. Molecular structure, $H-O-\underset{O}{\overset{O}{\underset{\|}{\overset{\|}{S}}}}-O-H$. Density = 1.842. Boils at 617° F.

115. Preparation of Sulphuric Acid.—This substance, which has been known from very early times, is, perhaps, one of the most important, if not the most important, known in chemistry, and is manufactured on an enormous scale, in order to supply the great demand arising from its manifold uses in the arts.

As now manufactured commercially, it is obtained by the oxidation of sulphurous oxide in the presence of water (steam), the oxygen necessary for this purpose being carried to it by some of the oxides of nitrogen. This oxidation takes place in enormous leaden chambers, on which the dilute acid produces no sensible action. The sulphurous oxide is obtained either by the burning of sulphur or the roasting of any pyrites, a general name given to natural metallic sulphides. The oxides of nitrogen are obtained by the decomposition of any nitrate. As the sulphurous oxide and oxides of nitrogen pass through the chambers (generally three), into which jets of steam are forced, the sulphuric acid is formed, and collects in a thin layer of water that covers the bottom of the chamber.

The sulphuric acid so formed is too weak for ordinary use, and requires to be concentrated. This is done by boiling it first in lead stills, and afterwards in platinum stills, until it acquires a density of 1.842.

Fig. 74 shows the apparatus suitable for the preparation of sulphuric acid for a class experiment. The flask, A, contains any materials for generating sulphurous oxide, such, for example, as copper and sulphuric acid; the bottle, B, generates the nitrous fumes, as, for example, by the action of nitric acid on copper. The sulphurous oxide and nitrous fumes meeting in the large jar, C (filled with dry air), cover it with white, shining crystals. If, now, steam be introduced, from E, these crystals disappear, and sulphuric acid is formed and collects at the bottom, and red nitrous fumes fill the jar.

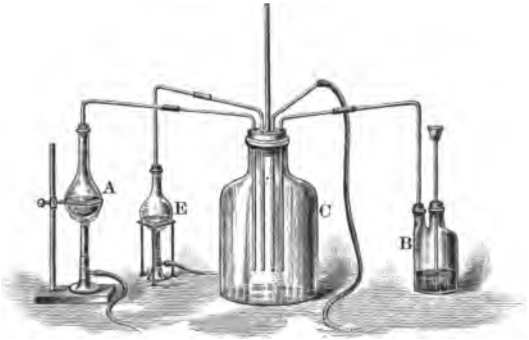


Fig. 74.—Preparation of H_2SO_4 in Laboratory Scale.

The oxide of nitrogen appears to act by carrying the oxygen of the air to the sulphurous oxide, thus oxidizing it into sulphuric acid, thus:

$$NO_2 + SO_2 + H_2O = H_2SO4 + NO$$

Nitrogen Peroxide + Sulphurous Oxide + Water = Sulphuric Acid + Nitrogen Dioxide.

Then the nitrogen dioxide takes oxygen from the air, and becomes nitrogen peroxide, thus:

$$NO + O = NO_2$$

Nitrogen Dioxide + Oxygen = Nitrogen Peroxide.

A very concentrated variety of sulphuric acid, called *fuming sulphuric acid*, or *Nordhausen sulphuric acid*, is obtained by decomposing sulphate of iron by heat.

116. Properties of Sulphuric Acid.—Sulphuric acid is a dense, colorless, oily liquid, commonly known as *oil of vitriol.* It possesses a strong affinity for water; the fuming of Nordhausen sulphuric acid on exposure to the air, being due to its condensing the aqueous vapor. This affinity for water is so great that vegetable matter when immersed in sulphuric acid is charred by the abstraction of its water, or of its hydrogen and oxygen. The combination of sulphuric acid and water is attended with a contraction of the liquid, and the evolution of heat. Sulphuric acid is powerfully corrosive, and causes painful burns when allowed to remain on the skin. It is so powerfully acid that it will redden litmus even when diluted with a thousand times its bulk of water. It is decomposed by a red heat when pure, and at a much lower temperature in the presence of copper. Since it contains two atoms of hydrogen, sulphuric acid is dibasic.

The presence of sulphuric acid, either free or in combination, is readily detected by the dense white precipitate it forms with barium chloride.

Experiment 29.—Pour sufficient saturated solution of sugar and water into a tall beaker (a thin glass vessel capable of standing sudden changes of temperature) to one-fourth fill it. Add an equal bulk of sulphuric acid, and stir with a glass rod. A charring action will ensue, and a dense mass of charcoal will be formed, which will more than fill the beaker. For this reason a soup-plate should be placed under it. Observe that at the same time the mixture becomes very warm.

Experiment 30.—Write on paper with a pointed glass rod dipped into a weak solution of sulphuric acid in water. Allow the writing to dry; it will then be invisible. Now hold the paper over a hot stove and the writing will appear as a jet black. This is due to the carbonization of the paper by the acid.

Experiment 31.—Gradually add to a given quantity of water two and one-half times its bulk of strong sulphuric acid, constantly stirring. When the mixture has cooled, immerse a sheet of unsized paper in the acid, and allow it to remain therein for about twenty seconds. Then remove, and thoroughly wash in water, and the paper will be found to have become converted into a substance resembling parchment. The change is due to an action of the acid on the cellulose of the paper.

SELENIUM.

Se = 79.5. Density of vapor = 79.5. Quantivalence = II., IV., VI. Free molecule, Se=Se. Discovered by Berzelius in 1817.

117. Properties and Uses of Selenium.—Selenium and tellurium are rare elements, possessing many properties in common with sulphur.

Selenium was obtained by Berzelius from a red deposit found in a sulphuric acid chamber. It occurs in nature in very small quantities as a selenide. There are two allotropic modifications, one soluble in carbon disulphide, and the other insoluble. The soluble variety occurs both as a brick red powder and as a black crystalline powder. The insoluble variety possesses a metallic lustre and a dark color. Its specific gravity is 4.8. At a high temperature, it boils, and deposits scarlet flowers of selenium. It burns in the air with a bright blue flame, forming selenious oxide, SeO_2, which possesses a characteristic odor resembling rotten horse-radish. It combines with hydrogen to form a gas with a very disagreeable odor.

The most valuable property possessed by metallic selenium is the variation that occurs in its conducting power for electricity by the action of light. On being exposed to the light, its electrical conducting power is instantly diminished as much as one-half. This property has been utilized by Bell in the construction of his *telephote*, an instrument by means of which he is enabled to hold telephonic communication with any speaker along a ray of light, instead of along a metallic wire, as is usual.

TELLURIUM.

Te = 128. Vapor density = 128. Quantivalence = II., IV., VI. Free molecule, Te=Te.

118. Properties of Tellurium.—Tellurium occurs in nature, associated with gold, silver, and other metals, in still smaller quantities than selenium. Like selenium, it possesses a metallic lustre. Its color is a silvery white. It burns in air with a blue flame, forming white vapors of telluric dioxide. At a high temperature, it gives off a golden-yellow vapor. With hydrogen it forms a colorless gas, having a disagreeable smell resembling that of sulphuretted hydrogen. Its oxides combine with water to form tellurous and telluric acids.

The name tellurium is derived from *tellus*, the earth. Selenium, which was discovered after tellurium, takes its name from Σελήνη, the moon, from its similarity to tellurium.

SYLLABUS.

Sulphur occurs in nature, both in the free state and in combination. Its principal source is in the volcanic districts of Italy.

Native or pure sulphur was originally called brimstone.

Crude sulphur is purified or refined by distillation. The vapor, condensed by cool surfaces, forms what is called flowers of sulphur. The refined sulphur is cast in cylindrical moulds, called roll sulphur.

Sulphur is a tasteless, inodorous, and nearly opaque solid. It is quite brittle, and, when held in the hand, emits a crackling noise, due to the fractures caused by local expansions.

Sulphur exists in three allotropic modifications, two of which are crystalline, and the other amorphous.

An allotropic modification of a substance is one in which the substance can assume a form possessing physical and chemical properties different from what it ordinarily possesses, without altering its chemical composition.

Sulphur, when first melted, is a mobile liquid. As the temperature increases, the liquid becomes very viscid; but at a still higher temperature it again becomes mobile.

Sulphur possesses energetic chemical affinities. It combines with many of the elements and burns in the air with a pale blue flame.

Sulphur combines with hydrogen to form a gas, which is called hydrogen sulphide, or sulphuretted hydrogen. It possesses an extremely disagreeable odor.

Hydrogen sulphide is readily prepared by the action of dilute sulphuric acid on ferrous sulphide.

Hydrogen sulphide is a colorless gas possessing a sweetish taste, but an extremely disagreeable odor. It burns in the air with a pale blue flame. It is valuable as a reagent, producing characteristic precipitates with most of the metallic salts. By cold or pressure it is converted into a transparent liquid.

When sulphur is burned in the air, a dense gas is produced, called sulphurous oxide, which possesses a highly suffocating odor. This gas is soluble in water, and must, therefore, be collected over mercury, or by simple displacement.

Sulphurous oxide is readily converted by cold or pressure into a colorless, transparent liquid, that, when exposed to the air, evaporates with great rapidity, producing a temperature considerably lower than zero.

Sulphurous oxide gas does not support ordinary combustion. Several of the metals, however, ignite spontaneously when thrown into the gas.

In the presence of moisture, sulphurous oxide is a powerful bleaching agent. It owes this property to the nascent hydrogen produced by the decomposition of the water.

The nascent state is the condition of an element when just liberated from combination. Substances in the nascent state possess properties different from those ordinarily possessed, on account of the bonds, which are free or open when the elements are just liberated from combination.

Sulphur combines with oxygen to form a substance called sulphuric oxide. It is a white, silky, fibrous substance, possessing a very powerful attraction for water, by which it is converted into sulphuric acid.

Sulphuric acid is one of the most important substances known to chemistry. It is very variously employed in the arts, and is manufactured in enormous quantities.

Sulphuric acid is manufactured commercially, by the oxidation of sulphurous oxide by nitrous fumes in the presence of water. The nitrous fumes act as a carrier of the oxygen of the air to the sulphurous oxide. The process is carried on in huge chambers lined with sheet-lead, the acid liquor from which is afterwards concentrated by evaporation.

Fuming sulphuric acid, or Nordhausen sulphuric acid, is obtained by decomposing ferrous sulphate by heat.

Sulphuric acid is a dense, colorless, oily liquid, that is commonly known as oil of vitriol. It possesses so strong an affinity for water that it removes it, or its constituents, from vegetable substances immersed in the acid, thereby charring them.

The presence of sulphuric acid is readily detected by means of the dense white precipitate which it produces with a soluble barium salt.

Selenium and tellurium are rare, elementary substances, that possess properties very similar to sulphur. They form compounds with hydrogen and oxygen, resembling those formed by these elements with sulphur.

The electrical conductivity of selenium is less in the light than in the dark.

QUESTIONS FOR REVIEW.

How does sulphur occur in nature? What is the principal source of the sulphur of commerce? By what name is crude sulphur known?

Describe the process employed for refining crude sulphur. How are flowers of sulphur formed? How is roll sulphur prepared?

Name some of the characteristic physical properties of sulphur. Explain the cause of the peculiar crackling noise heard when a roll of sulphur is held in a warm hand.

Describe the manner of preparing crystals of sulphur by fusion: by solution. How is the amorphous variety of sulphur obtained?

Describe the dimorphous, amorphous, and allotropic modifications of sulphur.

Describe the changes produced in the liquidity of sulphur by a gradual increase of temperature.

Describe an experiment by which the production of flowers of sulphur is illustrated.

Give some of the chemical properties of sulphur.

How is hydrogen sulphide prepared? Describe its characteristic properties. For what purpose is it extensively employed in the laboratory?

What substance is produced when sulphur is burned in air?

How may sulphurous oxide be most conveniently prepared? Describe the apparatus employed for this purpose. How must this gas be collected? Why?

State some of the characteristic properties of sulphurous oxide. To what does sulphurous oxide owe its bleaching properties?

Will sulphurous oxide support combustion? How can you prove this?

What is meant by the phenomena of the nascent state? Why should the elements possess different properties when just liberated from combination, than some time afterwards?

Describe any experiment for showing the bleaching properties of sulphurous oxide.

Describe the appearance and properties of sulphuric oxide.

How is sulphuric acid prepared commercially? Why is it such an important compound?

What is the main office of the nitrous fumes employed in the manufacture of sulphuric acid?

How is fuming or Nordhausen sulphuric acid prepared?

Describe the characteristic properties of sulphuric acid. How may its great affinity for water be shown experimentally?

Describe the process for converting paper into artificial parchment.

Describe some of the properties of selenium. What are the principal sources of selenium?

What valuable electrical property does selenium possess?

Describe some of the properties of tellurium. In what respects do selenium and tellurium resemble sulphur?

SECTION III.

NITROGEN, PHOSPHORUS, BORON, ARSENIC, ANTIMONY, AND BISMUTH.

CHAPTER V.

NITROGEN.

N = 14. Density = 14. Compared with air = 0.9714. Molecular weight = 28. Quantivalence = I., III., V. Free molecule, $N \equiv N$. Discovered by Rutherford in 1772.

119. Occurrence in Nature and Preparation.—Nitrogen constitutes the greater bulk of the atmosphere. It can readily be obtained by depriving the atmosphere of its oxygen.

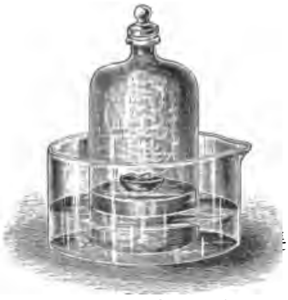


Fig. 75.—Preparation of Nitrogen.

The simplest method of doing this is by igniting a piece of phosphorus in a capsule, floating on a water surface, and placing a bell jar over it as shown in Fig. 75. The first effect is to cause the air in the jar to expand and to escape therefrom in bubbles. Soon, however, as the oxygen of the air is removed to support the combustion of the phosphorus, the water rises in the bell jar to supply its place. The dense white fumes that collect on the sides of the jar, are one of the oxides of phosphorus. They are, however, soon dissolved by the water, and disappear, and a transparent, colorless gas remains in the jar. This gas is nearly pure nitrogen.

120. Properties of Nitrogen.—Nitrogen is a colorless, tasteless, inodorous gas, that does not support respiration or combustion. It possesses but feeble chemical affinities, combining directly with but few of the elementary substances. Indirectly, however, it can be combined with very many of them. It is slightly soluble in water.

Animals immersed in nitrogen soon die, not from any poisonous property of the gas, but merely from the absence of oxygen.

Experiment 32.—Immerse a lighted taper in a jar of nitrogen. The flame will be instantly extinguished.

* * *

AMMONIA.

$NH_3 = 17$. Density = 8.5. Compared with air = 0.596. Discovered by Priestley in 1774.

121. Preparation.—A small quantity of ammonia is nearly always present in the air in the form of ammonium carbonate. Ammonia is most conveniently prepared by the action of heat on a mixture of equal parts of quicklime (calcium oxide), and ammonium chloride (sal-ammoniac). As soon as the mixture is made, it is placed in a Florence flask so as to partly fill it, the rest of the flask being filled with quicklime, to free the liberated gas from water. The reaction which occurs when the flask is heated is as follows, viz.:

$$\underset{\text{Ammonium Chloride}}{2NH_4Cl} + \underset{\text{Calcium Oxide}}{CaO} = \underset{\text{Ammonia}}{2NH_3} + \underset{\text{Calcium Chloride}}{CaCl_2} + \underset{\text{Water.}}{H_2O}$$

Ammonia gas is collected over mercury.

122. Properties of Ammonia.—Ammonia is a transparent, colorless gas, possessing a caustic taste, and a pungent, irritating odor, producing a flow of tears. It is collected over mercury, but may be obtained nearly pure by upward displacement. It is readily converted by cold or pressure into a transparent, colorless liquid.

It is soluble in water to a marked degree, water, at the freezing-point, dissolving 1000 times its volume of the gas. A solution of the gas in water forms the aqua ammonia of the apothecaries. This is, in reality, *ammonium hydrate,* and has the composition NH_4OH. When gently heated it evolves ammonia gas. Ammonia gas contains three volumes of hydrogen and one volume of nitrogen, condensed to two volumes, as may be shown by decomposing the gas by passing it through a red-hot porcelain tube and collecting the gaseous products.

Ammonia gas is not combustible in air, but will burn in pure oxygen; when mixed with oxygen, in certain proportions, it is explosively combustible. It is irrespirable; and when breathed in a pure state produces death. In small quantities, however, it produces a pleasant exhilaration when breathed, and is sometimes given in small doses, diluted with water, for the same purpose.

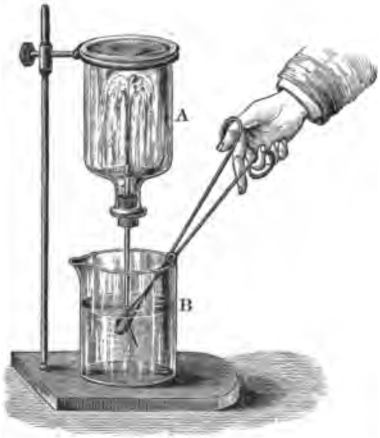


Fig. 76.
Rapid Absorption of Ammonia Gas by Water.

Experiment 33.—The rapidity with which ammonia gas is absorbed by water is very well shown by the following experiment: A bottle, A, Fig. 76, filled with ammonia gas, and fitted with a cork and glass tube, sealed at the outer end, is inverted over a vessel, B, containing cold water. On breaking the end of the tube under the water, the latter is spouted in a jet into A, and soon fills it.

Experiment 34.—Pour some of the water used in the preceding experiment, or a few drops of ammonium hydrate, into a solution of reddened litmus—the blue color is at once restored, the ammonia neutralizing the acid. Acid stains may be removed from clothes by rubbing them with aqua ammonia. If a solution of blue cabbage be used instead of reddened litmus, the addition of ammonium hydrate causes the color to change to green.

Experiment 35.—The gradual oxidation of ammonia is illustrated as follows: Suspend a small platinum spiral, S, Fig. 77, over some ammonia solution contained in the beaker, A; gently heat the beaker, and force a current of oxygen gas through the ammonia by the tube, C. The ammonia and oxygen, that come in contact with the spiral, combine and heat it to redness, and white fumes of ammonium nitrate fill the beaker.

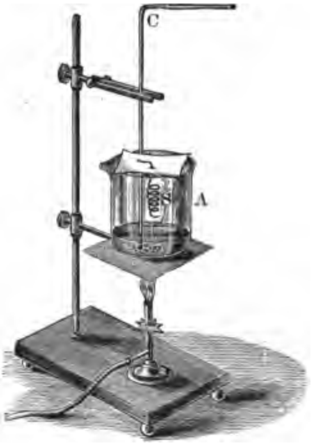


Fig. 77.
Gradual Oxidation of Ammonia Gas.

123. Nitrogen Chloride, and Nitrogen Iodide.—Nitrogen combines with chlorine and iodine to form frightfully explosive compounds, that appear to have the following composition: NCl_3 and NI_3. The former is more dangerous than the latter. Either often explodes on the slightest touch, or even spontaneously. It is therefore recommended that no effort be made by the student to produce either of these substances.

124. The Ammonium Theory.—Ammonia forms a large number of crystallizable salts, in which a compound radical, NH_4, called ammonium, takes the place of a metallic base of the salt. Thus, NH_4Cl, ammonium chloride, is similar to KCl. NH_4NO_3, ammonium nitrate, is similar to KNO_3. The radical ammonium is capable of combining with mercury and forming an amalgam (a compound consisting of a metal combined with mercury), just like a true metal.

Experiment 36.—To form ammonium amalgam, pour a small quantity of mercury into a porcelain mortar (a vessel suitable for pounding and pulverizing substances with a pestle), and covering it with a piece of cardboard, provided with a hole for the introduction of the pestle, throw into it a few small pieces of metallic sodium, and mix gently with the pestle; they will unite violently with the mercury with the emission of light and heat, and form a *sodium amalgam.*

Now throw this amalgam into a tall precipitating jar, nearly filled with a saturated solution of ammonium chloride, and the sodium amalgam becomes changed into ammonium amalgam, becoming very much larger in volume. This amalgam possesses the lustre of mercury, with the consistency of butter. It is quite unstable, and soon decomposes into ammonia, hydrogen, and mercury.

125. Ammonium Chloride, or Sal-Ammoniac.—This substance consists of the radical ammonium, combined with chlorine. It is a compact, white, fibrous crystalline salt, having a sharp, salty taste. It is soluble in water, and volatilizes at high temperatures. It was formerly obtained from animal matters, but is now prepared from the water through which illuminating gas has been passed, at the gas-works, for the purposes of purification.

Experiment 37.—The formation of ammonium chloride, by the direct union of ammonia gas and hydrochloric acid, may be shown by pouring a small quantity of ammonium hydrate in a tall glass jar, and a quantity of hydrochloric in another similar jar, and then inverting the latter and placing it over the former. The two jars will be at once filled with dense, white fumes of ammonium chloride.

126. Other Salts of Ammonium.—*Ammonium nitrate* may be formed by adding nitric acid to ammonium hydrate. The solution deposits large, transparent, colorless crystals, so readily soluble in water as to produce a marked lowering of the temperature when rapidly dissolved therein.

The principal use of ammonium nitrate is for the production of the ordinary laughing-gas, now largely employed as an anæsthetic (a substance possessing the power of temporarily depriving a person of sensation). The laughing-gas is produced from the nitrate by decomposing it by heat.

Ammonium carbonate. There are several carbonates of ammonium. Ammonium bi-carbonate is formed by passing carbonic acid through aqua-ammonia. It possesses acid properties.

Ammonium sulphate may be formed by neutralizing aqua-ammonia with sulphuric acid. It is a colorless salt with a sharp taste.

Ammonium sulphydrate is obtained by passing hydrogen sulphide through ammonium hydrate. This material is extensively employed in the laboratory as a reagent, giving characteristic precipitates with many solutions of metallic salts.

127. Compounds of Nitrogen and Oxygen.—Though nitrogen and oxygen do not combine directly, they may be indirectly united in the following proportions, viz.:

N_2O = Nitrogen monoxide, or nitrous oxide.
$N_2O_2 = 2(NO)$ = " dioxide.
N_2O_3 = " trioxide.
N_2O_4 = " tetroxide, or nitrogen peroxide.
N_2O_5 = " pentoxide, or nitric anhydride.

All of these combinations produce gaseous substances, the volume of the resulting gas being always equal to two volumes.

The trioxide and the pentoxide combine with water to form nitrous and nitric acids respectively.

◆

Nitrogen Monoxide (Laughing-Gas).

$N_2O = 44$. Density = 22. Compared with air = 1.527. Discovered by Priestley in 1776.

128. Preparation and Properties.—Nitrogen monoxide is prepared by the action of heat on ammonium nitrate. This salt, on moderate heating, breaks up into nitrogen monoxide and water, thus:

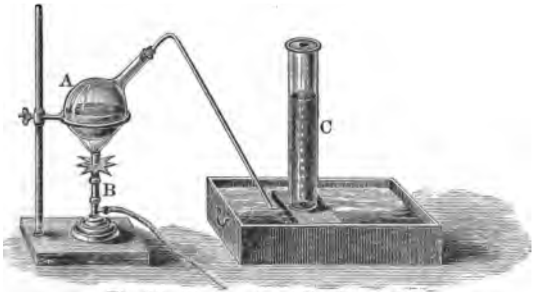


Fig. 78.—Preparation of Laughing-Gas.

$$NH_4NO_3 + \text{Heat} = N_2O + 2H_2O.$$
$$\text{Ammonium Nitrate} + \text{Heat} = \text{Nitrogen Monoxide} + \text{Water.}$$

It is necessary to avoid heating too high, as in this case other gases are evolved. The ammonium nitrate may be placed in the flask, A, Fig. 78, and decomposed by the heat of the Bunsen burner, B. The gas is collected in C, placed over a pneumatic trough.

Nitrogen monoxide is a colorless, transparent gas, possessing a pleasant taste and smell. It is but slightly soluble in water, over which it may be collected. It supports combustion almost as vigorously as oxygen. When breathed it produces the curious effect of ringing in the ears, followed by insensibility.

Before complete insensibility ensues, a species of delirious excitement is produced, during which the person breathing the gas, often laughs boisterously, and is otherwise greatly excited.

In this condition surgical, dental, and other operations may be performed on a person without producing any pain, and the gas is now very generally employed for such purposes. Death, however, may follow prolonged inhalation. Care should be exercised before breathing the gas, to ascertain that it contains no chlorine, or other irrespirable gases.

Nitrogen monoxide is liquefied by considerable pressure. The liquid so produced evaporates with extreme rapidity, producing an intense cold. A mixture of liquefied nitrogen monoxide and carbon disulphide, if caused to evaporate very rapidly, produce a temperature as low as —220° F.

A fragment of burning charcoal thrown on the surface of liquid nitrogen monoxide floats thereon, and continues to burn with brilliant scintillations. Here we may observe the curious phenomena of a liquid whose temperature is many degrees below zero, supporting the combustion of a body heated to a full incandescence.

Experiment 38.—Dip a lighted candle into a jar of nitrogen monoxide. It will burn with increased brilliancy. Withdraw the candle and extinguish it, so as to leave a glowing wick; again introduce it into the gas, and it will instantly be relighted.

Nitrogen Dioxide.

NO = 30. Density = 15. Compared with air = 1.039. Discovered by Hales in 1772.

129. Preparation and Properties. — Nitrogen dioxide or nitric oxide is prepared by the action of nitric acid on metallic copper. The copper is introduced into a Wolfe bottle, W, Fig. 79, and the acid poured in through the safety-tube, S. The gas may be collected in the jar, B, over cold water. The reaction is as follows, viz.:

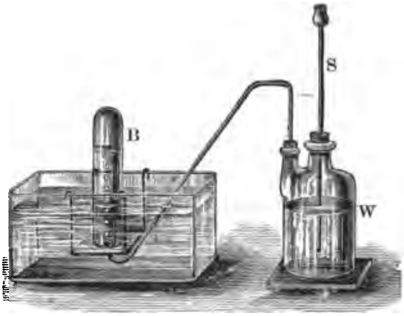


Fig. 79.—Preparation of Nitric Oxide.

$$3Cu + 8HNO_3 = 3Cu(NO_3)_2 + 4H_2O + 2NO.$$

This gas is called the dioxide because it contains twice as much oxygen as the monoxide, N_2O.

Nitric oxide is a colorless and exceedingly irrespirable gas, that, on exposure to the air, at once combines with oxygen, and forms the characteristic red fumes of nitrogen tetroxide. It supports the combustion of iron and phosphorus, provided they be thoroughly ignited before introduction into the gas. A few drops of carbon disulphide, thrown into a jar of the gas, diffuse throughout it, and form a mixture that, when lighted, instantly enflames, producing a bluish flash.

The nitric oxide obtained by the above process is never, however, pure, being invariably associated with free nitrogen and nitrous oxide. To obtain it chemically pure, the gas is passed into a saturated solution of cold ferrous sulphate, with which it forms a curious compound, soluble in water. The blackish-brown liquid so obtained readily yields chemically pure nitric oxide, on being heated. The gas produced by the direct action of nitric acid on copper is, however, sufficiently pure for most purposes.

Experiment 39.—Fill a bell jar with nitrogen dioxide, and, holding as shown in Fig. 80, remove the cover. Instantly a dense cloud of dark reddish-brown fumes of nitrogen tetroxide is formed from the combination of the nitrogen dioxide with the oxygen of the air.

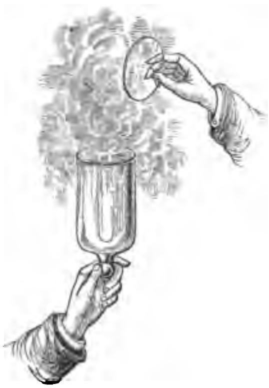


Fig. 80.—Nitrogen Dioxide Exposed to the Air.

130. The other Oxides of Nitrogen.—The remaining oxides of nitrogen are comparatively unimportant.

Nitrogen Trioxide, N_2O_3, is a bluish liquid that has a low boiling-point. It is comparatively stable at both high and low temperatures, but decomposes spontaneously at intermediate temperatures.

Nitrogen Tetroxide, or *Peroxide,* N_2O_4, or NO_2, is at low temperatures, a colorless, mobile liquid, that emits reddish vapors at ordinary temperatures. It is irrespirable and corrosive. In the presence of sufficient water it is decomposed into nitrous and nitric acids, thus:

$$N_2O_4 + H_2O = HNO_2 + HNO_3$$

Nitrogen Peroxide + Water = Nitrous Acid + Nitric Acid.

It is the nitrogen peroxide that plays so important a part in the production of sulphuric acid in the process of the leaden chambers. In the presence of steam the nitrogen peroxide undergoes the following decomposition, viz.:

$$3NO_2 + H_2O = 2HNO_3 + NO$$

Nitrogen Peroxide + Water = Nitric Acid + Nitrogen Dioxide.

The nitrogen dioxide subsequently combines with the oxygen of the air, and reproduces nitrogen peroxide, as already explained, thus:

$$NO + O = NO_2$$

Nitrogen Dioxide + Oxygen = Nitrogen Peroxide.

Nitrogen pentoxide, or *Nitric Anhydride,* N_2O_5, is a white, crystalline solid that is very unstable, often exploding spontaneously. It possesses powerful oxidizing properties. It volatilizes in dry air, and deliquesces in moist air, producing nitric acid.

Nitric Acid.

$HNO_3 = 63$. Specific gravity of liquid = 1.52.

131. Occurrence in Nature.—Nitric acid occasionally occurs free in the atmosphere, being formed therein, by the direct combination of nitrogen and oxygen, through the action of atmospheric electricity. It occurs in large quantities, in combination, as nitrates. The principal of these natural nitrates are those of potassium, calcium, and sodium; in various parts of India, and in South America, in the desert of Atacama, the deposits are very large.

Nitrogenous matter, oxidized in the air, produces ammonia; but when alkaline matters, such as lime, potash, or soda are present, nitric acid results, and nitrates are formed. This would especially occur in hot climates, where oxidation is rapid, and accounts for the presence of the nitrate beds of the previously named localities.

132. Preparation of Nitric Acid.—Nitric acid is prepared commercially by the action of comparatively weak sulphuric acid on some natural nitrate, such, for example, as sodium nitrate. The mixture of sodium nitrate and sulphuric acid is placed in a cast-iron retort, R, Fig. 81, heated by means of the furnace, F. The nitric acid vapors are conducted by the tube, B, into a series of stoneware receivers, C, C, C, where condensation occurs. The reaction is as follows, viz.:

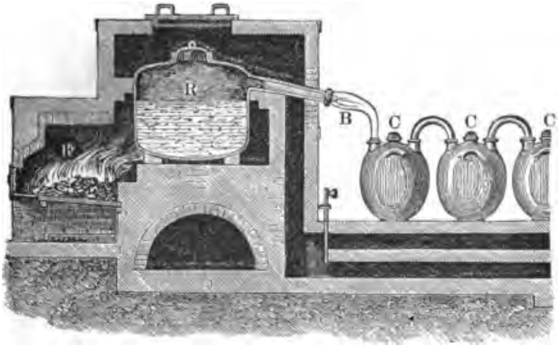


Fig. 81.—Commercial Preparation of Nitric Acid.

$$H_2SO_4 \quad + \quad NaNO_3 \quad = \quad NaHSO_4 \quad = \quad HNO_3$$

Sulphuric Acid + Sodium Nitrate = Acid Sodium Sulphate + Nitric Acid.

Experiment 40.—In order to conveniently prepare a small quantity of nitric acid, place in a retort, R, Fig. 82, equal weights of potassium nitrate and concentrated sulphuric acid. Pass the neck of the retort, without corking, into a receiver, V, cooled by a small stream of water. On the application of heat, the nitric acid vapors are condensed in V.

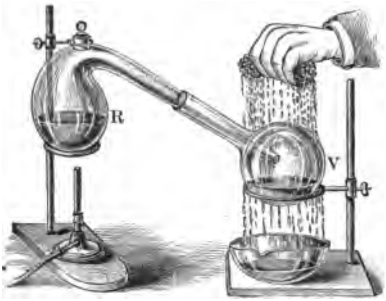


Fig. 82.—Preparation of Nitric Acid.

133. Properties of Nitric Acid. — Nitric acid is a colorless liquid that fumes strongly when exposed to the air, and gradually assumes a yellowish color. Its density is 1.5. It has a peculiar smell, and possesses a powerful attraction for water. It is an extremely corrosive acid, causing painful burns when touched to the skin in a concentrated state, and, when weaker, staining it a peculiar yellow color. It boils at a lower temperature than water, suffering partial decomposition into nitrogen peroxide, oxygen, and water.

It will be observed, that nitric acid is an acid hydrate, one of the hydrogen atoms in water being replaced by the compound radical nitryl, NO_2, thus:

$$H—O—H \qquad (NO_2)—O—H$$

Water. Nitric Acid.

Nitric acid is a powerful oxidizer, oxidizing many of the non-metallic and most all the metallic elements.

Experiment 41.—Mix equal parts of concentrated nitric and sulphuric acids in a porcelain dish. Place in a beaker some slightly warmed oil of turpentine. Fasten the beaker to a long stick and cautiously pour the oil of turpentine into the acid. Intense combustion occurs, due to rapid oxidation of the turpentine. The nitric acid, prepared by the preceding experiment, is particularly suitable for this purpose.

Experiment 42.—Using the beaker attached to the stick, pour some nitric acid on red-hot charcoal. Intense combustion occurs with the development of the red fumes, due to decomposition of the acid.

In the action of nitric acid on metallic bodies, the character of the reaction is markedly influenced by the degree of concentration or dilution of the acid. These peculiarities are due to the feeble affinity between the constituent elements of nitric acid. For example, either silver or copper dissolved in nitric acid probably displaces the hydrogen, but no hydrogen is set free, the nascent hydrogen abstracting oxygen from a part of the nitric acid, and forming water. Dilute nitric acid rapidly dissolves iron; concentrated acid has no action on it.

Zinc thrown into very dilute nitric acid is dissolved without disengagement of gas, a part of the acid being reduced by the nascent hydrogen into ammonia. Zinc nitrate and ammonium nitrate are formed, thus:

$$Zn + 2HNO_3 = Zn(NO_3)^2 + H^2$$

Zinc + Nitric Acid = Zinc Nitrate + Hydrogen.

$$2HNO_3 + 4H_2 = 3H_2O + (NH_4)NO_3$$

Nitric Acid + Hydrogen = Water + Ammonium Nitrate.

134. Aqua Regia, or *royal water*, is an old name, still retained, given to a mixture of nitric and hydrochloric acids. It possesses powerful solvent properties, dissolving, when heated, even platinum and gold. It owes its solvent property to the liberation of chlorine by the action of the heat, aided by the oxidizing powers of the nitric acid.

CHAPTER VI.

PHOSPHORUS, BORON, ARSENIC, ANTIMONY, AND BISMUTH.

PHOSPHORUS.

P = 31. Density = 61.9 (anomalous). Compared with air = 4.32. Molecular weight = 124. Quantivalence = I., III., V. Free molecule, $P_2 \equiv P_2$. Discovered by Brandt in 1669.

135. Occurrence in Nature.—The ease with which phosphorus is oxidized prevents its occurrence in a free state in nature. In combination, however, it is widely distributed, being found in all fruitful soils, and forming a necessary constituent of plants. It exists in the bones and tissues of animals, and also in their nervous matter. When the worn-out animal tissues are replaced by new tissues, the phosphorus of the old tissues is excreted in the urine as a phosphate. Phosphorus also occurs in the mineral kingdom as various phosphates. An impure calcium phosphate (*sombrerite*) forms the source of most of the phosphorus of commerce.

136. Preparation of Phosphorus.—Phosphorus is prepared commercially from bones. The bones are calcined and mixed with dilute sulphuric acid; the following reaction occurs, viz.:

$$\begin{array}{ccccccc} Ca_3(PO_4)^2 & + & 2H_2SO_4 & = & CaH_4(PO_4)^2 & + & 2CaSO_4 \\ \text{Tricalcium Phosphate} & + & \text{Sulphuric} & = & \text{Calcium Acid} & + & \text{Calcium} \\ \text{(burned bones).} & & \text{Acid} & & \text{Phosphate} & & \text{Sulphate.} \end{array}$$

The calcium acid phosphate is separated from the insoluble calcium sulphate by filtering. The solution is evaporated to dryness, and the solid residue heated to a redness, thus converting the calcium acid phosphate into calcium metaphosphate, thus:

$$\mathrm{CaH_4(PO_4)^2} + \text{Heat} = \mathrm{2H_2O} + \mathrm{Ca(PO_3)^2}$$

Calcium Acid Phosphate + Heat = Water + Calcium Metaphosphate.

The calcium metaphosphate is finally mixed with charcoal and strongly heated in earthenware retorts, R R R, Fig. 83, that are suitably connected with earthenware pipes, S, S. Decomposition occurs and the phosphorus vapor distils and is condensed in the earthenware pipes, that dip below the surface of water in the vessels, B B. The carbon monoxide that passes off with the phosphorus vapor, bubbles through the water in B B, and escapes into the air. The reaction may be represented as follows, viz.:

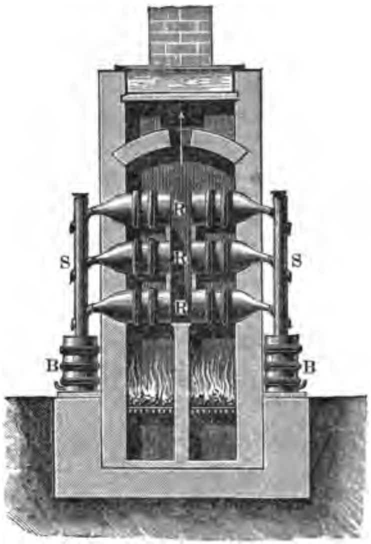


Fig. 83.—Production of Phosphorus.

$$\mathrm{2Ca(PO_3)^2} + \mathrm{5C} = \mathrm{Ca_2P_2O_7} + \mathrm{5CO} + \mathrm{P_2}$$

Calcium Metaphosphate + Carbon = Calcium Pyrophosphate + Carbon Monoxide + Phosphorus.

The phosphorus found in the vessels, B B, generally contains particles of carbon and other impurities; to separate it from these it is melted under water and cautiously passed through chamois leather, when it is run into glass or copper tubes and moulded into sticks.

The principal use of phosphorus, in the arts, is in the manufacture of the ordinary friction matches. Some is also employed as a poison for vermin.

137. Properties of Phosphorus.—When recently fused, phosphorus is a transparent and almost colorless, flexible, waxy solid, that is readily cut or scratched. It has a peculiar odor somewhat resembling garlic. It is insoluble in water, but is readily soluble in carbon disulphide. It is extremely inflammable, and is ignited in the air by the smallest friction, burning with the production of dense white fumes. It is, therefore, always kept under water. Phosphorus is luminous in the dark, and takes its name from φῶς, light, and φέρω, I bear.

There are several allotropic modifications of phosphorus, viz.:

1st. The common colorless variety possessing the properties above mentioned. This is a crystalline variety.

2d. Amorphous phosphorus possesses properties quite different from common phosphorus; its color is brownish red; it is not luminous in the dark, and is insoluble in carbon disulphide. Unlike the colorless variety, it is not poisonous. The red phosphorus is sometimes converted into a black amorphous phosphorus.

Experiment 43.—So great is the affinity of phosphorus for oxygen that if oxygen be forced from the bag, B, Fig. 84, against melted phosphorus in the glass vessel, V, surrounded by hot water in the vessel, O, a flash of light will be observed whenever the bubbles of gas touch the phosphorus.

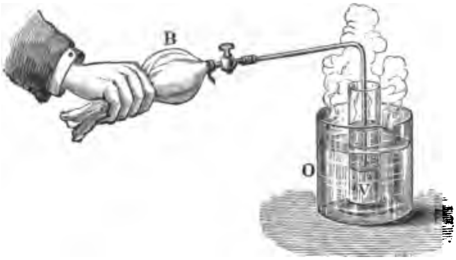


Fig. 84.—Combustion of Phosphorus under Water.

Experiment 44.—Dissolve a small piece of phosphorus in some carbon disulphide. Hang a piece of unglazed paper on a retort stand and pour the dissolved phosphorus over the paper. In a few moments the paper will burst into flame; for, as the carbon disulphide evaporates, the phosphorus is left on the paper in a state of extreme division, in which it is rapidly oxidized.

138. Anomalous Density of Phosphorus Vapor.—As we have already seen, the density of an elementary substance, compared with hydrogen, should always equal the weight of one atom of the substance. Now the density of phosphorus vapor is 61.9, which is the weight of two atoms of phosphorus. Therefore the vapor of phosphorus presents this curious anomaly, that it contains in the same volume twice as many atoms as do the other elements. The same is true of the vapor of arsenic. The explanation of this anomaly is that the molecules of phosphorus and arsenic vapors each contain four atoms. We have already seen that the molecules of hydrogen and other gaseous elements contain two atoms; and since equal volumes contain equal numbers of molecules, the density of phosphorus vapor should be twice its atomic weight.

Hydrogen Phosphide.

$PH_3 = 34$. Density $= 17$. Compared with air $= 1.134$. Discovered by Gengembre in 1783.

139. Preparation and Properties.—Hydrogen phosphide, or phosphoretted hydrogen, is readily prepared by the action of heat on a strong solution of potassium hydrate, in which fragments of phosphorus have been placed. The phosphorus is placed in the retort, R, Fig. 85, containing the potash solution. The tube, S, connected with the neck of the retort, passes below the surface of water in the vessel, V. The following reaction occurs when the retort is heated, viz.:

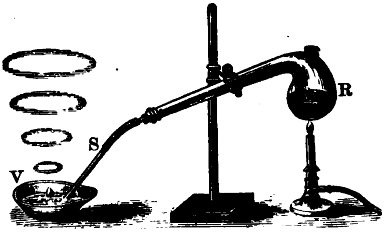


Fig. 85.—Preparation of Hydrogen Phosphide.

$$\begin{array}{ccccccccc} 3KOH & + & 4P & + & 3H_2O & = & 3KH_2PO_2 & + & PH_3 \\ \text{Potassium Hydrate} & + & \text{Phosphorus} & + & \text{Water} & = & \text{Potassium Hypophosphite} & + & \text{Hydrogen Phosphide.} \end{array}$$

Hydrogen phosphide is a colorless gas, with an exceedingly unpleasant odor, similar to that of the pole-cat. It is spontaneously inflammable in the air; the bubbles of gas that escape from the water in the preceding experiment, bursting at once into flame, with the production of curious vortex rings of smoke that enlarge on rising. The pure gas is not spontaneously inflammable. It appears to owe this property to a liquid hydrogen phosphide, P_2H_4.

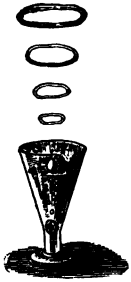


Fig. 86.
A Property of Calcium Phosphide.

When calcium phosphide, prepared by passing the vapor of phosphorus over fragments of heated lime, is thrown into water, it is decomposed by the water into spontaneously inflammable hydrogen phosphide, and calcium hypophosphite.

Phosphorus combines with chlorine, iodine, bromine, and fluorine, to form numerous compounds, none of which are very important.

The compound with fluorine, PF_5, is, however, of theoretical interest, because it is a gas that is stable at high temperatures.

140. Compounds of Phosphorus and Oxygen.—Phosphorus combines with oxygen to form two oxides, viz.:

P_2O_3 = Phosphorus Trioxide.
P_2O_5 = " Pentoxide.

There are three acids, viz.:

H_3PO_2, that is, $PH(OH)_2$ = Hypophosphorous Acid.
$P_2O_3 + 3H_2O = 2H_3PO_3$, or $2[P(OH)_3]$ = Phosphorous "
$P_2O_5 + 3H_2O = 2H_3PO_4$, or $2[PO(OH)_3]$ = Phosphoric "

The last two correspond to phosphorous and phosphoric oxides. There is no known oxide corresponding to the first acid.

141. Hypophosphorous Acid, or H_3PO_2, is prepared by boiling phosphorus with an alkaline solution, as in the method already described for producing spontaneously inflammable hydrogen phosphide. This acid is remarkable for its reducing properties, reducing salts of mercury and silver. It is decomposed by a strong heat into hydrogen phosphide, and phosphoric acid. This acid is monobasic, that is, only one of its hydrogen atoms is replacable.

142. Phosphorous Acid, or H_3PO_3, is formed by the gradual oxidation of phosphorus in moist air, but is more conveniently prepared by the decomposition of phosphorus trichloride by water, thus:

$$PCl_3 + 3H_2O = H_3PO_3 + 3HCl$$

Phosphorus Trichloride + Water = Phosphorous Acid + Hydrochloric Acid.

By evaporating the solution, a crystalline mass of phosphorous acid remains. It has a garlicky, acid taste, and deliquesces on exposure to the air. It is a powerful reducing agent. This acid is dibasic, two of its hydrogen atoms being replacable. Its salts are called *phosphites.*

143. Phosphoric Acid.—The white fumes observed when phosphorus is burned in air are phosphorus pentoxide, P_2O_5, or the anhydride of phosphoric acid. This substance has a powerful affinity for water, hissing when thrown into it, and forming phosphoric acid. It forms three definite hydrates with water, thus producing three definite and characteristic acids, viz., the *common* or *orthophosphoric acid, pyrophosphoric acid,* and *metaphosphoric acid;* their compositions are as follows, viz.:

H_3PO_4 = Common or orthophosphoric acid.
$H_4P_2O_7$ = Pyrophosphoric acid.
HPO_3 = Metaphosphoric acid.

Their derivation from P_2O_5 is readily seen, viz.:

$$\begin{aligned}
P_2O_5 + 3H_2O &= H_6P_2O_8 = 2(H_3PO_4) = \text{Orthophosphoric.}\\
P_2O_5 + 2H_2O &= H_4P_2O_7 \qquad\qquad\quad = \text{Pyrophosphoric.}\\
P_2O_5 + H_2O &= H_2P_2O_6 = 2(HPO_3) \;\;= \text{Metaphosphoric.}
\end{aligned}$$

Orthophosphoric acid is tribasic, that is, all three of its hydrogen atoms are replacable, though but one or two may be replaced. Pyrophosphoric acid is dibasic, and metaphosphoric acid is monobasic. Some of the preceding acids are capable of still further modifications, thus giving rise to a great variety of salts.

Orthophosphoric acid may be prepared by dissolving amorphous phosphorus in moderately dilute nitric acid. The solution on evaporation yields crystals of the acid. They readily deliquesce on exposure to the air, and possess an agreeable acid taste.

Pyrophosphoric Acid. When crystals of orthophosphoric acid are heated for a considerable time, at about the temperature of boiling water, they lose water, and are converted into pyrophosphoric acid.

Metaphosphoric acid is formed when the ordinary phosphoric acid is heated to a red heat. This acid is sometimes called *glacial phosphoric acid,* in reference to its vitreous or icy appearance. It is distinguished from the preceding by producing an abundant white precipitate with the albumen of white of eggs. Orthophosphoric acid gives a yellow, and pyrophosphoric acid a white, precipitate with silver salts. The metaphosphoric acid also gives a white precipitate with a silver salt.

◆

Boron.

B = 11. Specific gravity = 2.68. Molecular weight = 22? Quantivalence = III. Free molecule, $B \equiv B$? Discovered by Gay Lussac and Thenard in 1808.

144. Preparation and Properties.—The principal natural source of boron is boracic acid and its various salts. There are some doubts whether this element has yet been obtained perfectly pure.

Boron may be prepared by the action of sodium on boric oxide. These substances are fused in a retort, together with sodium chloride, which is added merely to increase the fusibility. The reaction is as follows, viz:

$$\underset{\text{Boric Oxide}}{2B_2O_3} + \underset{\text{Sodium}}{3Na_2} = \underset{\text{Sodium Borate}}{2Na_3BO_3} + \underset{\text{Boron.}}{B_2}$$

The sodium borate is separated from the boron by solution, when the boron remains as an amorphous, greenish powder, which, when sufficiently heated in the air, burns and produces boric oxide. Boron acts as a powerful reducing agent.

Boron combines with aluminium, and forms a crystalline compound that assumes the form of exceedingly hard, brilliant, black octahedra. They were formerly regarded as an allotropic modification of boron.

Boron combines with chlorine, bromine, and fluorine, and forms BCl_3, a colorless liquid; BBr_3, a colorless liquid; and BF_3, a colorless gas. They are unimportant.

145. Boron Trioxide, and Boric Acid.—There is but one oxide of boron, viz., B_2O_3, which, combined with water, forms H_3BO_3, or boric acid. A large part of the commercial boric acid of Europe is obtained from the Tuscan lagoons, in which it exists in solution. The waters of these lagoons are concentrated, by boiling by the heat of jets of steam from the neighboring volcano, which are condensed in the lagoon. Boric acid also occurs in considerable quantities in Peru and Chili, in Central California, and in the western part of the United States.

Boric acid crystallizes in shining hexagonal plates. It is a weak acid. When its aqueous solution is boiled, it volatilizes along with the vapor of water. It dissolves in alcohol, to the flame of which it imparts a greenish color. It imparts a characteristic brown color to paper soaked in turmeric solution. Like phosphoric acid, there exists an orthoboric acid, a pyroboric acid, and a metaboric acid.

ARSENIC.

As = 75. Density (anomalous) = 150. Compared with air = 10.37. Molecular weight = 300. Quantivalence = I., III., V. Free molecule, $As_2 \equiv As_2$. Discovered by Schroeder in 1694.

146. Occurrence in Nature, and Extraction.—Arsenic occurs in nature in the pure or native state, and, in combination, in certain ores and minerals. These ores are principally arsenides of iron, nickel, or cobalt, or various sulphides of arsenic. The most important of these are arsenical iron and nickel, arsenical pyrites or mispickel, realgar, and orpiment.

The arsenic is separated from these minerals by the simple process of heating in earthenware tubes. The arsenic is sublimed, and received in tubes of sheet-iron, inserted into and forming a prolongation of the earthenware tubes. The crude product thus obtained is purified by being mixed with a little charcoal and re-sublimed.

147. Properties of Arsenic. — When recently sublimed, arsenic presents a crystalline mass of a metallic lustre and a steel-gray color. Its specific gravity is 5.72. When heated, it volatilizes, and forms a vapor of a lemon-yellow color, having an odor of garlic. It readily oxidizes when heated in air, or in oxygen. Nearly all the soluble compounds of arsenic are exceedingly poisonous. The principal use of metallic arsenic, in the arts, is in the hardening of the lead used in shot.

* * *

Hydrogen Arsenide.

$H_3As = 78$. Density 39. Compared with air = 2.7. Discovered by Scheele in 1775.

148. Preparation and Properties. — Hydrogen arsenide, or arseniuretted hydrogen, may be readily obtained by the action of dilute sulphuric acid on zinc arsenide. The reaction may be represented as follows, thus:

$$Zn_3As_2 + 3H_2SO_4 = 2H_3As + 3ZnSO_4$$

Zinc Arsenide + Sulphuric Acid = Hydrogen Arsenide + Zinc Sulphate.

Hydrogen arsenide is one of the most poisonous gases known. A single bubble has been known to produce fatal results. It is a colorless gas, with the peculiar garlicky smell of arsenic vapor. It burns with a pale-blue flame, emitting white fumes of arsenious acid. It is soluble in water, and is decomposed by heat and chlorine.

When solutions containing arsenic are treated with acid and zinc, and caused to evolve hydrogen, a trace of arseniuretted hydrogen is always evolved. If the arsenical liquor be added to a hydrogen gas-bottle, H, Fig. 87, and a cool surface, such as a piece of white porcelain, B, be held in the flame of the gas, metallic arsenic will be deposited in the form of a black, shining mirror. This forms a delicate test for the presence of arsenic. It is known generally as Marsh's test, and is of great use in cases where poisoning by arsenic is suspected.

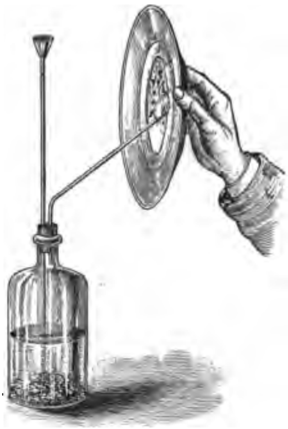


Fig. 87.—Marsh's Test.

Arsenic forms the following compounds with the halogen bodies, viz.: $AsCl_3$, an extremely poisonous, colorless, oily liquid; $AsBr_3$, a colorless, deliquescent, crystalline solid; AsI_3, a bright red crystalline solid; and AsF_3, a transparent and highly dangerous liquid.

149. Compounds of Arsenic and Oxygen.—When arsenical minerals are heated with free exposure to the air, or, as is technically called, roasted, arsenious oxide is formed, and may be separated from the other sublimed products. The crude mass thus obtained is re-sublimed.

Arsenious oxide, As_2O_3, when freshly made, is a transparent, colorless, vitreous mass, that soon, however, becomes changed at the surface to a milky white. This change is due to crystallization. The vitreous variety is amorphous.

Arsenious oxide is but slightly soluble in water, and therefore almost tasteless. It is soluble in hydrochloric acid. The aqueous solution is feebly acid, and may be regarded as *arsenious acid*, H_3AsO_3, though this substance has not been isolated. It acts as a violent corrosive poison, but in very small doses is much used in medicine. Its principal uses in the arts are in calico-printing, in glass-making, and in taxidermical (skin-preserving) preparations.

The most effective antidote for arsenious oxide is freshly-precipitated hydrated ferric oxide, which produces an insoluble arsenite.

The following are some of the tests for arsenious acid, viz.:

The solution, neutralized with ammonia, yields a green precipitate (Scheele's green), on the addition of copper sulphate.

Silver nitrate added to a solution of arsenious acid yields a canary-yellow precipitate of silver arsenite.

When it is desired to readily detect the presence of arsenious acid in, say a wall-paper, or cotton fabric, the color is dissolved in boiling hydrochloric acid, and a piece of bright copper foil placed in the solution. If arsenic be present, it will be deposited in the metallic state on the copper. This is known as Reinsch's test. To still further test it, the copper is washed, dried, and placed in a clean glass tube and heated. The arsenic is thus oxidized, and the arsenious oxide formed is volatilized, and condensed in the cooler parts of the tube.

Arsenic acid, H_3AsO_4, is readily prepared by heating arsenious oxide with nitric acid, which is decomposed, giving part of its oxygen to the arsenious acid. Arsenic acid occurs as a colorless, crystalline mass, having an unpleasant acid taste. It is not quite as poisonous as arsenious oxide. There are three modifications of arsenic acid, viz.: the orthoarsenic, the pyroarsenic, and the metaarsenic, corresponding to the similar phosphoric acids.

150. Compounds of Arsenic and Sulphur.—The native sulphides, As_2S_2, *realgar*, or arsenic disulphide, and *orpiment*, As_2S_3, or arsenic trisulphide, were known to the ancients, and may be produced artificially. There is also an arsenic pentasulphide, As_2S_5.

Arsenic disulphide, As_2S_2, or the red sulphide of arsenic, is prepared artificially by the direct fusing of arsenic and sulphur. It is a red, glassy mass, sometimes called ruby sulphur, and was formerly employed as a pigment. It is now employed, mixed with lime, in tanning, for the purpose of removing the hair from skins. It is also an important ingredient of a white fire, used at sea for a signal light.

Arsenic trisulphide, As_2S_3, or the yellow sulphide of arsenic, is formed when hydrogen sulphide is passed through a solution of arsenious acid. It is prepared commercially by subliming arsenious oxide mixed with sulphur. It was formerly used as a pigment, but its poisonous qualities have caused it to be almost entirely replaced by chrome yellow. It is used in the arts, in the printing of indigo dyes.

Arsenic pentasulphide, As_2S_5, may be prepared by fusing arsenic and sulphur in the proper proportions. It is comparatively unimportant.

ANTIMONY.

Sb = 120. Specific gravity = 6.7. Quantivalence = III., V. Molecular weight = 480? Free molecule, $Sb_2 \equiv Sb_2$ (?)

151. Occurrence and Preparation.—Though antimony possesses many of the physical properties of the metals, such, for example, as metallic lustre, and ability to conduct heat and electricity, yet its chemical relations unmistakably place it among the non-metallic bodies.

Antimony occurs in nature both in a pure state and in combination. It exists in greatest abundance as a sulphide.

The crude antimony sulphide is coarsely powdered and heated to dull red, in a suitably constructed furnace, until most of its sulphur is expelled. The roasted mass is then mixed with powdered charcoal, made into a paste with a strong solution of sodium carbonate, and heated to bright redness in crucibles, when the metal collects in the bottom of the crucible.

Antimony is a brilliant, bluish-white metal, so brittle as to be readily reduced to powder. It fuses at about a red heat, and slightly vaporizes at a higher temperature. When strongly heated in air, it burns brilliantly, evolving a dense, white smoke of antimonous oxide, Sb_2O_3.

Experiment 45.—Place a piece of metallic antimony on a lump of charcoal, and melt it by a blowpipe flame. Now drop the melted globule, from some little height, on a sheet of paper. It will break into numerous smaller globules, each of which makes a visible track of oxide on the paper, and leaves a train of smoke after it as it flies into the air.

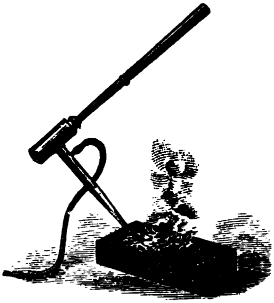


Fig. 88.—Melted Antimony.

The principal use of antimony, in th arts, is for the formation of certain alloys, of which *type metal*, consisting of one part of antimony, and three or four parts of lead, is the most important. The antimony imparts to the lead the valuable properties of hardness, and expansion on solidifying.

152. Hydrogen Antimonide, H_3Sb.—Though not yet obtained pure, its composition is probably as indicated. It may be obtained, mixed with hydrogen, by adding metallic antimony to the zinc in a hydrogen bottle, when the nascent hydrogen enters into combination with the antimony. The gas thus formed is inflammable, and deposits rings of metallic antimony on pieces of cold porcelain, like arseniuretted hydrogen.

Antimony rings are readily distinguished from arsenic rings. Antimony rings are not dissipated by heat, when protected by hydrogen gas, while arsenic rings are. Antimony rings are not readily dissolved by sodium hypochlorite, while arsenic rings are.

153. Compounds of Antimony and Chlorine.—There are two compounds of antimony and chlorine, viz.: the trichloride, $SbCl_3$; and the pentachloride, $SbCl_5$.

Antimony trichloride, or *butter of antimony*, is formed from antimony sulphide by the action of hydrochloric acid. It is a transparent, colorless, volatile, deliquescent solid. When thrown into water containing a small quantity of hydrochloric acid, it yields an abundant white precipitate which is an oxychloride. This was formerly called the powder of Algaroth. Antimony trichloride, is employed for bronzing gun-barrels to protect them from rust.

Antimony pentachloride, $SbCl_5$, is formed by the action of chlorine on hot, powdered antimony. It is a volatile, yellowish liquid, which emits dense, suffocating fumes on exposure to the air.

154. Compounds of Antimony and Oxygen.—The oxides of antimony are two in number, viz.:

Sb_2O_3 = Antimonous oxide.
Sb_2O_5 = Antimonic oxide.

Antimonous oxide, Sb_2O_3, is obtained by heating antimony to redness, while partially exposed to the air, as by covering the crucible containing the metal, with a second crucible containing an opening. On cooling, the upper crucible contains brilliant needle-shaped crystals. A higher oxide is formed by heating antimonous oxide for a long time in the air.

Antimonic oxide, Sb_2O_5, is formed by oxidizing antimony by heating it in strong nitric acid. A white powder is obtained, called metantimonic acid, $HSbO_3$, which, heated to redness, loses water and becomes Sb_2O_5.

155. Compounds of Antimony and Sulphur.—There are two sulphides of antimony, viz.: Sb_2S_3, antimonous sulphide, and Sb_2S_5, antimonic sulphide.

Antimonous sulphide, Sb_2S_3, or common sulphide of antimony occurs in nature in a crystallized condition in the grayish-black mineral *stibnite*. It may be obtained in an amorphous state as an orange-colored precipitate by the action of hydrogen sulphide on a solution of antimony chloride. This substance is used in the percussion cartridges of the needle-gun.

Antimonic sulphide, Sb_2S_5, is the orange-yellow precipitate formed by passing hydrogen sulphide through an acid solution of antimony pentachloride.

BISMUTH.

Bi = 210. Specific gravity = 9.8. Molecular weight = 840? Quantivalence = III., V. Free molecule, $Bi_2 \equiv B_2$?

156. Occurrence and Extraction.—Bismuth, like antimony, though possessing many of the physical properties of the metals, yet in its chemical relations, is best classified as a nonmetal of the same group as nitrogen, phosphorus, and arsenic.

Bismuth occurs in a native state, associated with a quartzy mineral from which it is extracted by simple melting.

157. Properties and Uses of Bismuth.—Bismuth is a hard, brittle metal of a whitish-gray color, and yellow lustre. By slow cooling it crystallizes in rhombohedra, greatly resembling cubes. Its specific gravity is 9.8, and its melting-point is 507° F. Bismuth is slightly volatile at high temperatures. It is unalterable in ordinary air, but at a red heat burns and forms bismuth oxide.

Bismuth possesses the curious property of lowering the melting-point of several alloys, one of which, called *fusible metal,* consisting of two parts of bismuth, two of tin, and one of lead, melts at a temperature below that of the boiling-point of water.

158. Compounds of Bismuth.—The compound of bismuth with chlorine, viz., bismuth trichloride, $BiCl_3$, is formed when finely divided bismuth is burned in chlorine. When bismuth trichloride is thrown into water, a white powder, the oxychloride, is formed. It is known as *pearl white,* and is used as a cosmetic.

Bismuth nitrate, $Bi(NO_3)_3$, is readily obtained by dissolving metallic bismuth in nitric acid. It crystallizes in colorless, deliquescent crystals, soluble in water containing a small quantity of nitric acid. By pouring this solution into an excess of water a white precipitate, much used in medicine and called sub-nitrate of bismuth, is formed.

Hydrogen sulphide precipitates brown bismuth sulphide from solutions of bismuth. All solutions of bismuth yield white precipitates when added to a large excess of water. Potassium chromate gives a yellow precipitate of bismuth chromate, freely soluble in dilute nitric acid, but insoluble in potassium hydrate.

Experiment 46.—Melt some bismuth in a crucible, and, allowing it to cool, so as to form a crust, pierce this crust and pour out the molten metal. On cooling, the crucible will be found filled with beautiful crystals of the metal.

Experiment 47.—Melt together one part by weight of tin, one of lead, and two of bismuth. Cast in the form of a spoon, or a rod, and stir boiling water with the same. The alloy will melt and remain molten below the surface of the water.

* * *

SYLLABUS.

Nitrogen constitutes the greater part by weight of the atmosphere. It can readily be obtained by depriving the air of its oxygen, by the combustion of phosphorus.

Nitrogen is a colorless, tasteless, inodorous gas, that does not support combustion or respiration. It possesses but feeble chemical affinities.

Ammonia gas is readily prepared by the action of heat on a mixture of ammonium chloride and quicklime. It is rapidly absorbed by water, and must, therefore, be collected over mercury, or by upward, dry displacement.

Ammonia is a transparent, colorless gas, with a caustic taste, and pungent, irritating odor. It is irrespirable, producing death if breathed in large quantities. In very small quantities it acts as a gentle, refreshing stimulant.

Ammonia gas is incombustible in air, but will burn in an atmosphere of oxygen.

Water absorbs 1000 times its bulk of ammonia gas forming a hydrate called ammonium hydrate, or aqua ammonia. This substance restores the blue color to reddened litmus solution or paper.

Nitrogen combines with chlorine and forms a frightfully explosive compound called nitrogen chloride.

The radical, ammonium, consists of ammonia combined with an additional hydrogen atom. It acts like a metal and forms regular salts by combination with acids.

Ammonium chloride, or sal ammoniac, is a whitish, fibrous, crystalline salt, obtained by neutralizing the ammoniacal liquor of the gas-works with hydrochloric acid.

Ammonium nitrate is a transparent, colorless, crystalline salt, formed by adding nitric acid to ammonium hydrate. The salt is deliquescent, and is used for producing laughing-gas, or nitrogen monoxide.

There are five compounds of nitrogen and oxygen, viz., nitrogen monoxide, nitrogen dioxide, nitrogen trioxide, nitrogen tetroxide, and nitrogen pentoxide. The trioxide and the pentoxide, combined with water, form nitrous and nitric acids respectively.

Nitrogen monoxide is obtained by the action of heat on ammonium nitrate. It is a colorless, transparent gas, having a sweetish taste, and pleasant smell. When respired, it produces a pleasant exhilaration, followed by loss of consciousness.

Nitrogen dioxide is obtained by the action of nitric acid on copper. It is a colorless gas, that is exceedingly irrespirable. Exposed to the air, it forms copious red fumes of nitrogen tetroxide.

Nitrogen trioxide is a bluish liquid with a low boiling-point.

Nitrogen peroxide or tetroxide, is an irrespirable, and corrosive vapor, that at a low temperature condenses into a colorless, mobile liquid.

Nitrogen pentoxide, or nitric anhydride, is a white, crystalline solid, that possesses a very great attraction for water, with which it forms nitric acid.

The natural nitrates are probably formed by the oxidation of nitrogenous matter in the presence of alkaline substances.

Nitric acid is prepared commercially by the action of sulphuric acid on some natural nitrate. It is a colorless liquid, that fumes when exposed to the air. It is extremely corrosive, and is a most powerful oxidizer.

Aqua regia is a common name given to a mixture of nitric and hydrochloric acids.

Phosphorus exists very widely diffused in nature, being found in all fruitful soils and entering very generally into the structure of animals and plants. It also exists in the mineral kingdom as various phosphates.

Phosphorus is prepared commercially by the action of dilute sulphuric acid on thoroughly calcined bones. A calcium acid phosphate is thus formed, which is evaporated to dryness, heated to a red heat, and mixed with charcoal and again strongly heated in earthenware vessels, when the phosphorus vapor distils off and is condensed in suitable vessels.

Phosphorus is largely used in the manufacture of matches. When recently fused it is a transparent, nearly colorless, waxy solid, insoluble in water and freely soluble in carbon disulphide. It is very inflammable, and is therefore kept under water. It is luminous in the dark and is very poisonous. There is also a red amorphous phosphorus, very unlike the above in its physical properties.

To the general statement that equal volumes of all elementary gases contain the same number of atoms, we must except phosphorus, the density of whose vapor shows that it contains twice as many atoms as an equal volume of hydrogen. The same is true of arsenic vapor.

Hydrogen phosphide is prepared by the action of heat on phosphorus, in the presence of a saturated solution of potassium hydrate. It is a colorless gas, of a peculiarly disagreeable odor, that is often spontaneously inflammable in air, producing curious rings of smoke.

Hypophosphorous acid is obtained by boiling phosphorus in an alkaline solution. It possesses powerful reducing properties and is monobasic.

Phosphorous acid is formed by the gradual oxidation of phosphorus in moist air. It is dibasic. Common phosphoric acid is formed by dissolving in water the white fumes evolved by burning phosphorus. It is tribasic.

There are three phosphoric acids, viz.: common or orthophosphoric; pyrophosphoric, and metaphosphoric. They consist of P_2O_5, combined with three, two, and one molecule of water respectively.

The natural sources of boron are boric acid and the borates.

Boron is prepared by the action of metallic sodium on boric acid at a high temperature. Boron is an amorphous greenish substance, which combines with oxygen at high temperatures, and forms boric oxide. Boron is a powerful reducing agent.

What was formerly believed to be a crystalline variety of boron is now known to be an impure compound of boron and aluminium.

Boric acid exists in large quantities in the Tuscan lagoons, from which it is extracted by evaporating their waters.

Boric acid is a weak acid, that crystallizes in hexagonal laminæ or plates. When dissolved in alcohol, it imparts to its flame a characteristic greenish tinge.

Arsenic occurs in nature both pure and in combination. Its principal ores are sulphides or arsenides, from which it is separated by sublimation.

Arsenic is a crystalline solid with a metallic lustre and a steel gray color. When sufficiently heated it volatilizes; its vapor is of a lemon-yellow color, and has an odor similar to that of garlic.

Hydrogen arsenide, or arseniuretted hydrogen, is a frightfully poisonous gaseous substance, obtained by the action of dilute sulphuric acid on zinc arsenide.

Marsh's test for arsenic in solution, consists in adding the suspected solution to a gas-bottle which is generating hydrogen. If arsenic is present, hydrogen arsenide is formed, and its presence detected by a metallic ring deposited on cold porcelain.

Arsenious oxide is formed by heating arsenic in contact with air. The uncrystallized variety is transparent and vitreous; the crystallized variety is milk white. When dissolved in water, arsenious acid is formed. Both the oxide and acid are very poisonous.

The best antidote for arsenious acid is freshly precipitated hydrated ferric oxide.

Arsenic acid is prepared by treating arsenious oxide with hot nitric acid.

Reinsch's test for arsenic consists in adding hydrochloric acid to the suspected substance, and introducing a piece of bright copper into the boiling solution. If arsenic be present, it is deposited in the metallic state on the copper.

There are three arsenic sulphides, viz.: As_2S_2, the disulphide, or realgar, a red substance; As_2S_3, the trisulphide, or orpiment, a yellow substance; and As_2S_5, the pentasulphide.

Antimony occurs in nature both pure and in combination. Its principal ore is a sulphide. It is a brilliant, bluish-white metal, that burns when heated in air, emitting a dense white smoke of antimonous oxide.

The principal use of antimony in the arts is in the formation of alloys; the most important of these is type metal.

There are two antimony chlorides, viz., The trichloride, and the pentachloride. There are two oxides, viz., Antimonous, and antimonic oxide. There are two sulphides, viz., Antimonous, and antimonic sulphide.

Bismuth occurs in nature in the pure state associated with a quartzy mineral. It is a hard, brittle mineral, of a whitish-gray color, and yellow metallic lustre.

Bismuth possesses the curious property of greatly lowering the melting-point of metals with which it is alloyed.

There are various compounds of bismuth; viz., the trichloride; the oxychloride, or pearl-white, a cosmetic; and the nitrate.

QUESTIONS FOR REVIEW.

What is the principal natural source of nitrogen?

Describe the method usually adopted for preparing nitrogen.

State the properties of nitrogen.

How is ammonia gas readily prepared? Enumerate its properties. How is ammonium hydrate prepared? Describe an experiment illustrating the rapidity of absorption of ammonia gas by water. What effect has aqua ammonia on red litmus?

Describe the principal property of nitrogen chloride. Explain the ammonium theory. Describe the formation of ammonium amalgam.

State the properties of ammonium chloride.

Describe any experiment by means of which this substance may be formed.

How is ammonium nitrate formed? For what is it generally employed? How are the carbonate and the sulphate formed?

Name all the oxides of nitrogen.

How is nitrogen monoxide prepared? By what other name is it known? Describe its properties. For what is it generally employed?

How is nitrogen dioxide prepared? Describe its properties.

Describe the other oxides of nitrogen.

What is believed to be the source of the free nitric acid sometimes found in the atmosphere?

How is commercial nitric acid generally prepared? How may it be prepared in the laboratory on a smaller scale?

State the properties of nitric acid. How may its oxidizing properties be experimentally illustrated?

What effect has the degree of dilution or concentration of nitric acid on its action on metallic bodies? How is aqua regia prepared? To what does it owe its solvent powers?

Name the natural sources of phosphorus.

From what source is commercial phosphorus obtained? Describe the process generally adopted for its preparation. State its properties.

What allotropic modification of phosphorus is there? How do its properties differ from those of ordinary phosphorus? What is the principal use of phosphorus in the arts?

How may phosphorus be rendered spontaneously inflammable?

In what respect is the vapor density of phosphorus anomalous?

How is hydrogen phosphide prepared? Describe its properties. Is it always spontaneously inflammable?

Name the oxides of phosphorus.

How is hypophosphorous acid prepared?

What characteristic property do the hypophosphites possess?

How is phosphorous acid prepared?

How is phosphoric acid prepared? What three distinct varieties of phosphoric acid exist? How are these derived from the pentoxide of phosphorus?

What are the natural sources of boron? How is boron prepared? Describe some of its properties. Does boron ever occur in a crystallized condition?

What is the composition of the only known oxide of boron?

Describe the manner in which boric acid is obtained. Name some of the properties of boric acid. In what respect does boric acid resemble phosphoric acid?

Name the principal natural sources of arsenic. Describe its properties. How is it separated from its compounds? What is the principal commercial use of metallic arsenic?

How is hydrogen arsenide prepared? Describe its properties. Describe Marsh's test for arsenic. Describe Reinsch's test.

How is arsenious oxide prepared? Describe the amorphous and the crystalline varieties. What are the properties of arsenious oxide? How is arsenious acid obtained from arsenious oxide? Name some of its tests.

Describe the sulphides of arsenic.

Why should antimony and bismuth be classed among the non-metals?

Describe the method adopted for the extraction of antimony from its ore. Give the properties of metallic antimony.

Name the compounds of antimony with hydrogen, chlorine, oxygen, and sulphur.

In what state does bismuth occur in nature? What are its properties? How is it extracted from the quartzy matter with which it is generally found associated?

What curious effect does bismuth produce on the melting-point of metallic substances with which it is alloyed?

Name some of the compounds of bismuth.

What is pearl white? How is bismuth nitrate prepared? How is the sub-nitrate of bismuth obtained?

Name some of the characteristic tests of bismuth.

SECTION IV.

CARBON AND SILICON.

CHAPTER VII.

CARBON AND SILICON.

C = 12. Specific gravity = 3.5 (Diamond). Quantivalence = II., IV. Molecular weight = 12? Free molecule, C?

159. Occurrence in Nature and Varieties.—The element carbon is widely distributed in nature, where it occurs both in the free state and in combination. It forms an essential element in the structure of plants and animals.

Carbon exists in at least three well-marked allotropic modifications, viz., as diamond, graphite, and amorphous carbon. The physical properties of these substances are widely different.

160. The Diamond consists of pure crystallized carbon. It varies in color from colorless to yellow, red, green, blue, brown, and occasionally black. It is found in various parts of the world, generally in connection with a granular quartz rock called itacolumite. The colorless variety is the most highly esteemed. The value increases rapidly with the weight. The specific gravity varies from about 3.52 to 3.55.

The composition of the diamond has been repeatedly shown by heating small diamonds to incandescence in a vacuum, when they swell and are converted into a substance resembling coke.

Some of the natural shapes assumed by the diamond are shown in Fig. 89. The hardness of the diamond is greater than that of any other known substance; this property renders it of great service in the cutting of gems, and in constructing drills for boring hard rocks. The diamond conducts neither heat nor electricity; it both refracts light powerfully, that is, turns it out of its course, and disperses it or separates it into different colors. This latter circumstance gives to the diamond its characteristic sparkle.

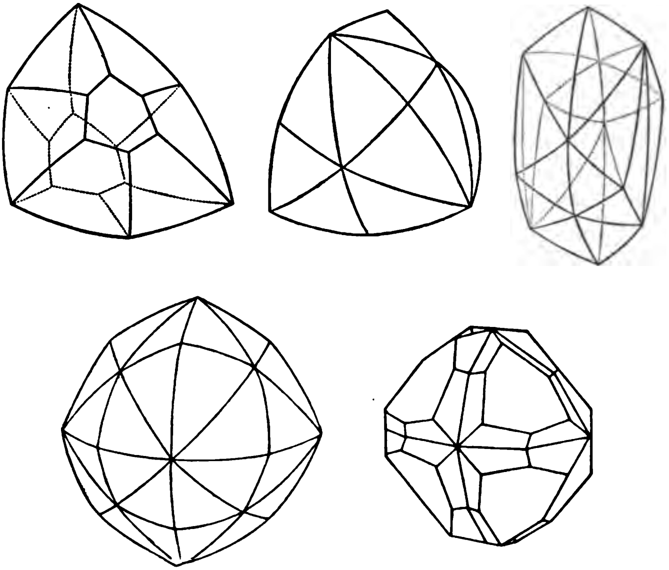


Fig. 89.—Crystalline Forms of the Diamond.

161. **Graphite, or Plumbago,** is another crystalline variety of carbon found in the earliest rocks where it has been exposed to a high temperature. Graphite, or plumbago, is the so-called black lead used in lead-pencils. It occurs naturally in thin, six-sided plates or laminae, and in compact granular masses. It has a steel gray color, and a greasy touch. It is so soft that it is readily scratched by the nail and leaves a black streak on paper. Pure graphite is a good conductor both of

heat and electricity. Its specific gravity varies from 2.01 to 2.58.

Graphite may be prepared artificially in two ways, viz.:

1st. By melting cast-iron containing a large excess of carbon, and allowing it to cool slowly, when the excess separates as bright scales of graphite.

2d. By heating artificial, amorphous carbon in the electric arc, when it is partially converted into graphite. The carbon electrodes, that is, the sticks or pencils employed in the production of the electric arc lights, are converted into graphite at the parts nearest the flame.

Graphite is used in the arts for a variety of purposes. It is largely employed in the manufacture of lead-pencils. The pencil-leads were formerly made by sawing the graphite into thin strips, which were afterwards mounted in wooden cases. They are now obtained by baking a stiff paste formed of powdered graphite and clay.

Finely powdered graphite is used in the process of electrotyping, for the purpose of rendering the wax mould, which is to receive the electric deposit, a conductor of electricity. For this purpose it is dusted over the surface.

Graphite is also largely employed as a lubricant (that which renders slippery) for machinery, etc. It is extensively employed in the manufacture of black lead crucibles, so highly esteemed for their fire-resisting qualities.

162. Amorphous Carbon occurs in a variety of forms. The following are the most important, viz.: lamp-black, gas retort carbon, coke, wood charcoal, and animal charcoal. These are all derived from the decomposition of organic substances.

Lamp-black is produced by the incomplete combustion of such substances as tar, turpentine, rosin, or petroleum.

The manufacture of lamp-black is conducted as follows, viz.: The carbonaceous substance, such as rosin, is placed in the pot, C, Fig. 90, where it is heated by the fire, F. The evolved vapors are burned in insufficient air, and give rise to a dense smoke of unburned carbon particles, which collect on canvas hung on the walls of the chamber, A. By lowering the funnel-shaped hood, B, the lamp-black is scraped from the walls. Lamp-black so made contains many impurities, such as oils and tars. It is separated from most of these by heating to redness. Lamp-black is employed for the manufacture of printing inks, India ink, and for a common black paint.

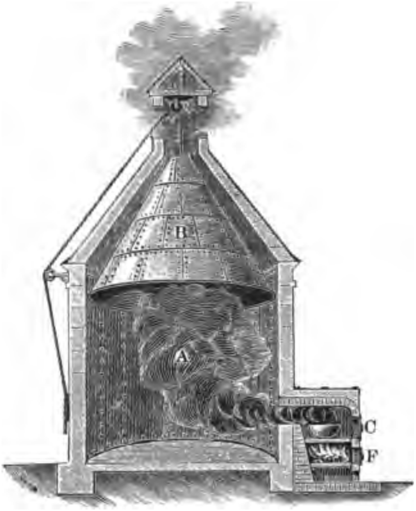


Fig. 90.—Manufacture of Lamp-black.

Gas carbon is the name given to the deposit that is found in the upper part of the retorts, in which common illuminating gas is prepared by the action of heat on bituminous coal. It is very nearly pure carbon, and is due to the decomposition of a hydrocarbon by heat. It is of an iron-gray color, and is exceedingly hard. It readily conducts both heat and electricity, and may be regarded as an amorphous variety of graphite. It is largely employed in the manufacture of carbon plates for batteries, and especially for the carbon points for the electric light.

For the manufacture of the carbon electrode, the gas carbon is finely pulverized, washed, and mixed with lamp-black or other pure, finely divided carbon, and made into a paste with syrup, tar, or other carbonizable liquid. It is then forced through an opening in a strong cylinder by hydraulic pressure, and baked at a red heat for several hours, while surrounded by sand or similar material to exclude the air. The carbons are then allowed to cool, and are removed, and again soaked and burned, in order to increase their density and electrical conducting power.

Coke is the residue from the heating of bituminous coal in absence of air. It is produced in large quantities in the manufacture of illuminating gas. It is used for smelting iron, and is frequently expressly manufactured for this purpose. Coke ignites at a much higher temperature than ordinary coal, and, since it is very nearly pure carbon, burns with much less smoke.

Charcoal is obtained by burning wood in an insufficient supply of air. A conical heap of wood is formed, provided with a central stack, *a*, Fig. 91, to carry off gaseous products. The heap is covered with turf and lighted at the bottom. Charcoal has a deep black color and glittering fracture. When properly burned, it gives, when struck, a ringing metallic noise. Its density and power of conducting electricity, and even heat, increase in a marked degree with the intensity and duration of the heat to which the charcoal has been exposed.

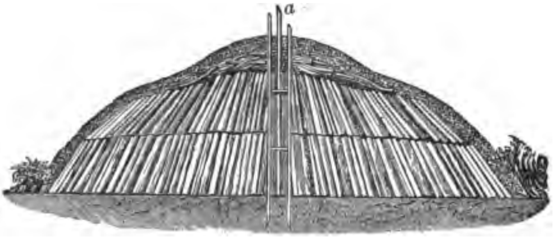


Fig. 91.—Manufacture of Charcoal.

Animal charcoal is obtained by the carbonization of animal substances. That obtained from bones is called *bone-black;* that from blood, *blood charcoal.* Animal charcoal possesses, as does also wood charcoal, but to a greater degree, the property of separating certain substances, such as metallic salts, from solution. It is largely employed in sugar refineries for decolorizing the raw sugar solution.

Charcoal is an extremely porous body, and possesses the property of absorbing gases and vapors to a remarkable degree, as shown by the following table, taken from Saussure.

One volume of charcoal, at ordinary temperature and pressure, absorbs of

Ammonia	90	vols.
Hydrochloric Acid	85	"
Sulphur Dioxide	65	"
Hydrogen Sulphide	55	"
Nitrogen Monoxide	40	"
Carbon Dioxide	35	"
Ethylene	35.	vols.
Carbon Monoxide	9.42	"
Oxygen	9.25	"
Nitrogen	6.50	"
Hydrogen	1.25	"

It is this property that renders charcoal so excellent a disinfectant, since it absorbs all disagreeable effluvia. Charcoal filters not only separate matters in suspension in the water, but render it purer by removing most of the soluble matters.

163. Coal may be regarded as another variety of amorphous carbon. Coal results from the decomposition of vegetable matter, under water, and therefore free from contact with the atmosphere. It occurs in immense deposits, which vary considerably in density, hardness, and composition, according to the heat and the pressure to which they have been exposed. All coal contains more or less hydrogen, oxygen, and nitrogen.

The principal varieties of coal are *anthracite*, *semi-bituminous*, and *bituminous*. Many of the bituminous coals soften and become pasty by heat; these are called *caking coals*. Some do not possess this property, and are called *non-caking* coals. Of these different varieties of coal, anthracite contains the greatest percentage of carbon.

164. Chemical Properties of Carbon.—Carbon is one of the most insoluble of all substances. It has no known solvent. It has a powerful affinity for oxygen, but only at high temperatures. Carbon heated to incandescence in free air, remains incandescent until consumed, being maintained at this temperature by the heat produced by the combustion. Carbonic acid gas is the product of the combustion of carbon in air.

The powerful affinity possessed by incandescent carbon for oxygen, renders it a valuable chemical agent in depriving compound substances of their oxygen. It is employed for this purpose in reducing the oxides of the metals to the metallic state.

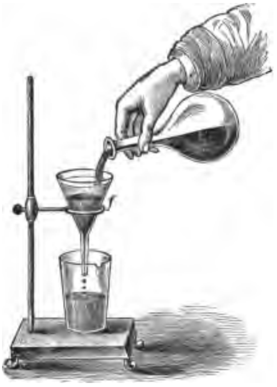


Fig. 92.
Decolorizing Power of Charcoal.

Experiment 48.—Prepare a dilute solution of indigo, and shake in a flask with freshly-prepared bone-black. Now pour the contents of the flask in a filter, *f*, Fig. 92, and the liquid that passes through will be colorless.

There are two oxides of carbon, viz.:

CO = Carbon Monoxide.
CO_2 = Carbon Dioxide, or Carbonic Acid Gas.

* * *

Carbon Monoxide.

$CO = 28$, Density $= 14$. Compared with air $= 0.967$.

165. Preparation.—The bluish flame that appears on the surface of a hard-coal fire is caused by the combustion of carbon monoxide. The combustion at the lower part of the fire produces carbon dioxide, which, passing through the heated coal above, is deprived of a part of its oxygen, and becomes converted into carbon monoxide.

Carbon monoxide is readily prepared by the action of strong sulphuric acid on oxalic acid. The oxalic acid is placed in the retort, R, Fig. 93, and enough sulphuric acid added to just cover it. On the application of heat, both carbon monoxide and dioxide are liberated. The latter is absorbed by a solution of potassium hydrate contained in the Wolfe bottle, B, while the former is collected over water in the bottle, S, which may, for convenience, be furnished with a jet for burning inflammable gases.

When most of the metallic oxides are heated with carbon in closed vessels, their oxygen combines with the carbon and forms carbon monoxide, the metal being reduced to the metallic state. In many of the processes for the reduction of metallic oxides, such, for example, as in the blast furnace for iron, carbon monoxide is given off in large quantities.

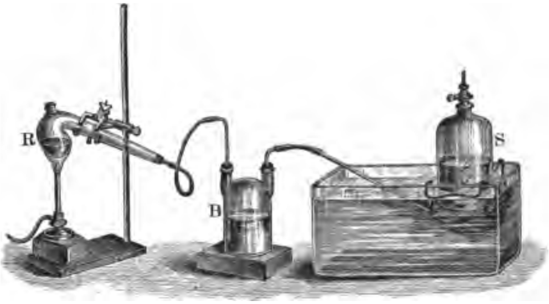


Fig. 93.—Preparation of Carbon Monoxide.

166. Properties of Carbon Monoxide.—Carbon monoxide is a colorless, tasteless gas, having a faint but peculiar odor. It is but slightly soluble in water, and is liquefied only by great pressure and cold. It does not support ordinary combustion, but burns readily in air with a blue flame, producing carbon dioxide.

Carbon monoxide is very poisonous, forming, as it does, a compound with one of the constituents of the blood. Even when considerably diluted with air it produces headache, giddiness, and even insensibility. The deaths caused by leaky furnaces, or charcoal fires, are undoubtedly due to the presence of this gas.

Carbon monoxide acts, under certain circumstances, as a compound radical, called *carbonyl*. This radical combines directly with chlorine to form $COCl_2$, or carbonyl chloride, or with oxygen to form carbonyl oxide or carbon dioxide.

Carbon Dioxide.

$CO_2 = 44$. Density = 22. Compared with air = 1.529. Discovered by Black in 1648. First analyzed by Lavoisier in 1776.

167. Natural Distribution.—Carbon dioxide, or carbonic acid, is one of the constituents of the atmosphere, in which it exists, normally, in about the proportion of a cubic inch of carbonic acid to a cubic foot of air. It is generally found in small quantities in all water exposed to the air, and exists in large quantities in certain mineral waters. It is frequently emitted from openings in the ground, and from the craters of extinct volcanoes.

The celebrated poison valley of Java, is a locality where large quantities of carbonic acid escape from the ground and collect in the lowest parts of the valley. In the grotto del Cane (grotto of the Dog), Italy, the heavy gas which collects near the floor is fatal to an animal, like a dog, whose stature is such that the head is near the ground, but is not at all injurious to a man, whose mouth is not reached by the gas.

The carbonic acid in the air is derived from the respiration of animals, and the gradual combustion of organic matter. Immense quantities of carbonic acid occur in the mineral kingdom in carbonates, such as limestone, and carbonates of magnesium, iron, barium, strontium, and zinc.

168. Preparation of Carbon Dioxide.—Carbonic acid is most conveniently prepared by the action of hydrochloric acid on some carbonate, such as limestone or marble.

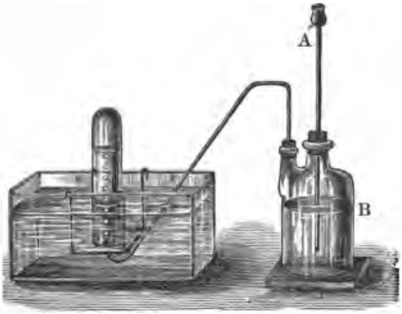


Fig. 94.—Carbonic Acid Apparatus.

The marble is broken into small pieces, and introduced into the Wolfe bottle, B, Fig. 94, and very dilute hydrochloric acid added by the funnel-tube, A. The gas is at once evolved, and may be collected over a pneumatic trough, or by dry downward displacement. The following reaction occurs, viz.:

$$\underset{\text{Calcium Carbonate}}{CaCO_3} + \underset{\text{Hydrochloric Acid}}{2HCl} = \underset{\text{Carbon Dioxide}}{CO_2} + \underset{\text{Calcium Chloride}}{CaCl_2} + \underset{\text{Water.}}{H_2O}$$

169. Properties of Carbon Dioxide.—Carbonic acid is a colorless gas, with a pungent odor and slightly acid taste. It is quite soluble in water, especially under high pressures, ordinary soda-water being simply water highly charged with this gas. At the temperature of melting ice it becomes, under a pressure of thirty-six atmospheres, converted into a clear, transparent, colorless liquid, about three-fourths as heavy as water. Liquid carbonic acid, relieved of pressure, evaporates very rapidly, and produces so very low a temperature that the portion of the liquid remaining unevaporated freezes. This property causes it to be frequently employed as a means for artificially obtaining intense cold.

Carbonic acid supports neither combustion nor respiration. It is slightly acid, reddening litmus solution.

Experiment 49.—Throw some sodium bi-carbonate in a tall glass jar, and pour a little dilute hydrochloric acid on it. As the gas is evolved it remains in the bottom of the jar, gradually displacing the air. If a lighted candle be carefully lowered into the jar, it will burn until it reaches the upper surface of the carbonic acid, but will be instantly extinguished on entering the gas.

Experiment 50.—Carbonic acid is a very heavy gas, and may be poured from a jar like so much water, as may be shown by pouring it from the jar, B, Fig. 95, on a candle burning at the bottom of the jar, A, when the flame is at once extinguished.

Experiment 51.—If a jar filled with air be carefully lowered into a larger jar containing carbonic acid, and drawn out again, mouth upwards, as it would be if employed for dipping water out of the larger jar, it will be found to be filled with carbonic acid, which has displaced the lighter air.

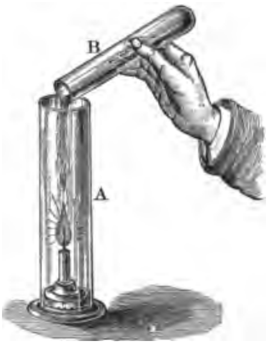


Fig. 95.—Experiment with Carbonic Acid Gas.

The well-known fire-extinguishers consist generally of apparatus by means of which a stream of water highly charged with carbonic acid gas is thrown on the fire.

170. Carbon Disulphide, CS_2.—When sulphur vapor is passed over incandescent carbon, a substance, called carbon disulphide, is formed, which is of great importance in the arts. The sulphur vapor is passed over red-hot charcoal contained in a close iron tube. Carbon disulphide is formed together with other sulphur compounds that impart to the crude substance its peculiarly disagreeable smell. These substances are separated from it by repeated redistillations.

The purified carbon disulphide is a clear, colorless, mobile liquid, having a sweetish and peculiar smell. It is highly refractory. Its specific gravity is 1.29, and its boiling-point 115° F. It is exceedingly inflammable, burning with a blue flame. Its vapor, when mixed with one-third its bulk of air, forms an explosive mixture.

Carbon disulphide is very poisonous, and even when inhaled in small quantities for a long time produces injurious effects on the nervous system.

Carbon disulphide is a powerful solvent for fats and oils, and is largely used in removing these substances from wool, and in extracting oils and fats generally. It is also a powerful solvent for caoutchouc, and is much used in the manufacture of India-rubber. It is also employed in various chemical manufactures.

171. Compounds of Carbon and Hydrogen.—The compounds of carbon and hydrogen are exceedingly numerous. They are known under the general name of hydrocarbons, or carbides of hydrogen. They are all volatile and combustible substances. The simplest of these hydrocarbons is methane, or marsh gas, CH_4. The next is C_2H_6, ethane, then C_3H_8, propane, etc. Their number is very great. They will be considered under organic chemistry, to which branch of the subject they properly belong. When hydrocarbons are burned in the air, the products of combustion are water and carbonic acid.

172. Nature of Combustion.—Combustion, such as ordinarily occurs in the atmosphere, consists in the union of the combustible body with the oxygen of the air. Nearly all the common substances that burn readily in the air, owe their combustibility to carbon and hydrogen. When the supply of air is insufficient to oxidize both the carbon and the hydrogen, the latter takes the oxygen, and the carbon is liberated as a soot or smoke. When plenty of air is present, the combustion is complete, and the smokiness of the flame absent.

Combustion, however, is not limited to the combination of bodies with oxygen; for, as we have already seen, many substances burn in atmospheres of chlorine, iodine, bromine, hydrogen, and sulphur.

The heat produced by combustion is caused by a wave motion, produced in an exceedingly tenuous medium, called the universal ether, by the collisions of the oxygen atoms and the atoms of the combustible body as they unite.

The quantity of heat developed by the combustion in oxygen of a pound of different substances varies with each substance. The amount generated by any substance is the same whether the combustion be rapid or whether it be slow. Therefore the intensity of the heat will necessarily depend on the rapidity of the combustion. Thus, one pound of wood charcoal will raise 73 pounds of ice-cold water to the temperature of the boiling-point; a pound of coal raises 60 pounds of water through a like difference of temperature.

Energy is either *kinetic* or *potential:* kinetic, when actually doing work; potential, when merely capable of doing work. Energy is either doing work, or ready to do work. Thus a man, by a cord and pulley, raises a 50-pound weight to the ceiling of a room. While the weight is moving, the energy he transfers to it, is kinetic. If the cord be fastened while the weight is near the ceiling, the energy becomes potential, and may be regarded as stored up in the weight; for, if at any time the cord be cut, the weight falls, and the potential energy again becomes kinetic, and all the energy put into the weight to raise it, is again given out as it falls to the floor.

Now all substances in an elementary state may be regarded as a weight raised a certain height. For example, take a piece of coal. Its carbon once existed in the atmosphere in the form of carbon dioxide, which was absorbed by the leaves of a plant, and under the influence of the sun's heat, the carbon atoms were separated (raised) from the oxygen atoms, and helped to form the woody fibre of the plant. Though buried in the earth untold thousands of years, they are ready at any time to fall towards and again unite with the oxygen atoms, and in doing so give out as heat, all the energy originally required to separate (or raise) them. The energy, therefore, developed by a given weight of a combustible body, burning in air, must depend on the amount of energy required to separate it from the oxygen with which it combines when burning; and, as the amount of energy required to effect this varies with different substances, so must the amount of heat they develop also vary.

The rapidity of combustion varies in different substances. It may be so rapid as to occur explosively, or it may be slow, or gradual. Ignition is the beginning of combustion. As we have already seen, all ordinary combustion takes place very rapidly in an atmosphere of pure oxygen. When the burning substance evolves combustible gases, the burning of these substances produces *flame*.

The rapidity of combustion is greatly influenced by the state of division of a body, as well as by its composition.

As a general rule, rapid combustion is hindered by the cohesion of the combustible substance; therefore, bodies burn better in a state of fine division than they do in large masses.

Experiment 52.—A rod of iron thrust into the flame of a Bunsen burner will not burn; but once overcome the cohesion of the iron rod by reducing part of it to filings, and throw these into the flame, and they will burn with brilliant scintillations.

Experiment 53.—Wrap a piece of lampwick around the open end of a long test-tube. Place in the tube a small quantity of lycopodium, a very minute seed of a species of moss. Wet the lampwick with alcohol and light it. Now throw out part of the lycopodium from the tube, so as to form a dust cloud. It is instantly ignited by the alcohol flame, and produces a blinding flash of light. Artificial lightning is often produced in this way at the theatres. Finely powdered rosin will answer for this purpose, but not as well as lycopodium.

173. The Nature of Flame.—Flame consists of the combustion of gases or vapors, producing so much heat that they become luminous, that is, incandescent.

The peculiarities of any flame may be conveniently studied from the flame of an ordinary candle. If this be carefully observed, it will be seen to consist of three distinct portions, viz.: 1st. A dark central cone, *a*, Fig. 96, surrounding the wick, and consisting of unignited gas, as may be shown by inserting a bent glass tube therein, when the gas escaping from its other end may be ignited.

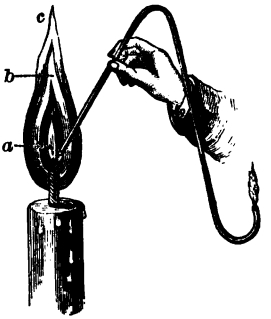


Fig. 96.—A Candle-Flame.

2d. A luminous cone, *b*, surrounding this, and consisting of partially or incompletely burned gas.

3d. A very hot, non-luminous cone, *c*, consisting of completely burned gases.

The cause of these cones is as follows: the heat, decomposing the wax or tallow of the candle, produces combustible gases and vapors that surround the wick; these gases and vapors hold very small carbon particles in suspension. On reaching the cone, *b*, these are raised to incandescence and produce the light. They are completely burned in the outer cone, *c*, where it receives plenty of air. The presence of the carbon in the central cone, is shown by the soot deposited on a piece of white porcelain held therein. The densities of gases also influence the luminosity of their flames.

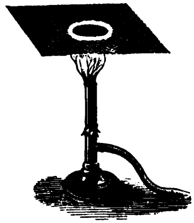


Fig. 97.
The Candle-Flame Hollow.

Since the air that causes the combustion of the gases is supplied from the outside, it is evident that a candle-flame is burning only on the outside, or, in other words, that such a flame must be hollow. This can be readily shown by holding a piece of wire gauze over the flame, as in Fig. 97. The edges only are luminous, while the central parts remain dark.

The central cone, *b*, will deprive most substances of their oxygen when held in it, and is therefore sometimes called the *deoxidizing cone*, or the *reducing flame*. The outer portion, *c*, gives oxygen to many substances, and is therefore sometimes called the *oxidizing cone*.

Experiment 54.—Hold a sheet of white paper, for a short time, horizontally in a candle-flame. A black ring of soot will be deposited on it from the hollow flame, and the paper within the ring will be unburned.

Experiment 55.—Quickly introduce the head of a phosphorus match into the dark, non-luminous cone, *a*, of a candle-flame, and although the wood will be charred where the edge of the flame touches it, the phosphorus will remain unignited.

In the Bunsen burner, or the oxyhydrogen blow-pipe, the flame is solid. This is one reason for the higher temperature of these flames.

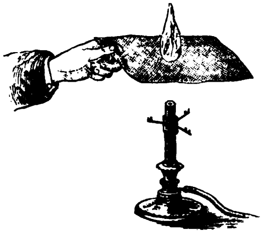


Fig. 98.
The Principle of the Safety-Lamp.

174. The Davy Safety-Lamp—Inflammable gases require a certain temperature before they will ignite. This fact can be shown, as in Fig. 98, by holding a piece of fine wire gauze over a Bunsen burner and then lighting the gas from above. The flame will not be communicated to the gas below the gauze, because the wire conducts the heat away from the lower parts so quickly that the temperature of the gas on this side of the gauze is too low to ignite it.

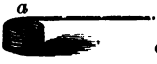


Fig. 99.
Effect of Temperature on Flame.

Experiment 56.—Coil a piece of moderately stout copper wire, as shown in Fig. 99, at *a*, and carefully place it over the flame of a candle. It will conduct the heat away from the flame so rapidly as to extinguish it.

This principle was ingeniously applied by Davy to the production of a safety-lamp for miners, obliged to enter atmospheres that at times contain explosive mixtures of inflammable gas and air, as is occasionally the case in coal mines.

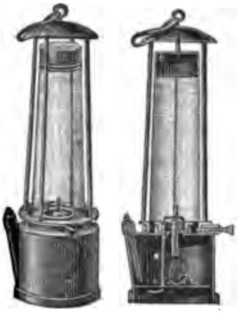


Fig. 100.
The Davy Safety-Lamp.

The Davy safety-lamp consists, as shown in Fig. 100, of an oil lamp surrounded by a fine wire gauze. Such a lamp may be safely carried into an explosive atmosphere, which may enter the meshes of the gauze, and burn inside the lamp, but the flame from which cannot be imparted to the gas outside the gauze on account of the cooling effect already explained.

The safety-lamp is not intended to be kept in an explosive atmosphere, but rather to warn workmen who may unexpectedly enter one. As soon as the workman notices the gas burning inside the lamp he should quit the gallery, and not reënter until it has been properly ventilated; for, should he remain too long, the gauze becomes heated up to the ignition point of the explosive gas.

The known failure, in some cases, of the safety-lamp to properly operate is to be ascribed to this cause, or to the effect of a draught, that blows the flame through the meshes of the protecting gauze, and so ignites the outside gas. Such draughts are especially caused by blasts fired in other parts of the mine. The Davy safety-lamp is of immense value to the mining interests of the coal districts.

175. **Manufacture of Illuminating Gas.**—Ordinary illuminating gas is obtained by exposing coal (generally bituminous) to the action of a red heat in retorts closed so as to exclude the air. Under these circumstances the coal undergoes a decomposition, or destructive distillation, producing a variety of products, which may be grouped under three heads, viz.: 1st. Coal gas, consisting of various inflammable gases, mainly hydrocarbons. 2d. Coal tar. 3d. Ammoniacal liquor.

The coal is placed in clay retorts, furnished at one end with a door for the introduction of the charge, and connected at the other end to an iron neck or pipe, furnished with an upright tube, through which the gaseous products pass into a series of pipes called the condensers. In these the gas is cooled, and deposits part of its ammonia, and most of its tarry matters. It is then passed through the scrubbers, which are tall vessels filled with coke, where it is washed by a spray of alkaline water (generally ammonia water). By this process it is freed from hydrogen sulphide, and other impurities. It is then passed over slacked lime in the *dry lime purifiers,* where the carbonic acid, and any remaining hydrogen sulphide, are absorbed. The gas, when thus purified, is stored in huge gasholders, from which it is distributed for consumption.

* * *

SILICON.

Si = 28. Specific gravity = 2.49. Molecular weight = 56? Free molecule, $Si=Si$? Quantivalence = IV. Discovered by Berzelius in 1825.

176. Occurrence in Nature.—Silicon does not occur in a free state in nature, but in combination with oxygen, as different varieties of quartz, flint, sand, etc., and as combinations of these with various bases, as silicates, it occurs second in abundance to oxygen, forming about one-fourth by weight of the earth's crust. Nearly all the geological strata contain an excess of silicon in some of its forms.

177. Modifications of Silicon, and Preparation.—Silicon may be obtained pure by heating dry potassium silico-fluoride, with metallic potassium or sodium, in an iron tube, when a violent reaction occurs. The tube on cooling is treated successively with cold and hot water, which removes the potassium fluoride, when silicon, or silicium, remains in the tube. The reaction may be represented as follows, viz.:

$$K_2SiF_6 + 4K = 6KF + Si$$

Potassium-silico Fluoride + Potassium = Potassium Fluoride + Silicon.

Thus prepared, silicon is an amorphous, dark brown powder, which, heated in the air, burns and produces silicon dioxide,

SiO_2. When heated to redness out of contact with air, it becomes denser and darker.

A crystalline variety of silicon is obtained by heating potassium silico-fluoride in a retort with metallic aluminium. The residue so obtained is then treated with hydrochloric acid, which leaves the silicon in the form of black, shining, hexagonal crystals, closely resembling graphite. Their specific gravity is 2.49. The reaction may be represented as follows, viz.:

$$\underset{\text{Silico-fluoride}}{\underset{\text{Potassium}}{3K_2SIF_6}} + \underset{\text{Aluminium}}{4Al} = \underset{\text{Fluoride}}{\underset{\text{Potassium}}{6KF}} + \underset{\text{Fluoride}}{\underset{\text{Aluminium}}{2Al_2F_6}} + \underset{\text{Silicon.}}{3Si}$$

178. Silicon Hydride, SiH_4.—This gas, which possesses many properties similar to hydrogen phosphide, is prepared by the action of hydrochloric acid on an alloy of silicon and magnesium. The alloy is placed in a bottle, A, Fig. 101, completely filled with water and furnished with a wide delivery-tube, B, also filled with water, and connected with a pneumatic trough. All the water used in this experiment must be freed from dissolved air by boiling. When hydrochloric acid is poured into the funnel-tube, C, the gas is evolved, and as each bubble escapes into the air, it ignites with the formation of a ring of smoke similar to that of hydrogen phosphide. This ring is formed of silicon dioxide, or silica. Silicon hydride is a colorless gas, insoluble in water freed from air.

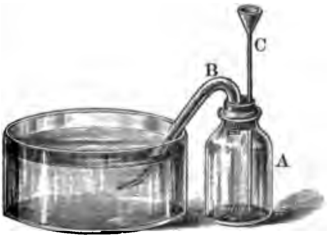


Fig. 101.—Preparation of Silicon Hydride.

179. Compounds of Silicon with Chlorine and Fluorine.—Silicon combines with chlorine and forms, among other compounds, *silicon chloride*, $SiCl_4$, a volatile colorless liquid, which is decomposed by water, and deposits a part of the silicic acid in a gelatinous mass.

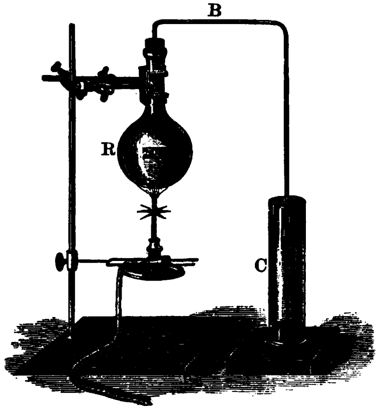


Fig. 102.—Preparation of Hydrofluosilicic Acid.

Silicon fluoride, SiF_4, is a colorless gas, that possesses a smell somewhat resembling hydrochloric acid; when passed into water it produces hydrofluosilicic acid, and silicic acid, which separates as a gelatinous mass. Silicon fluoride is prepared by heating calcium fluoride (Fluor-spar), and powdered glass or sand in a flask, R, Fig. 102, with an excess of strong sulphuric acid. The following reaction occurs, viz.:

$$\underset{\text{Calcium Fluoride}}{2CaF_2} + \underset{\text{Sulphuric Acid}}{2H_2SO_4} + \underset{\text{Sand}}{SiO_2} = \underset{\text{Silicon Fluoride}}{SiF_4} + \underset{\text{Calcium Sulphate}}{2CaSO_4} + \underset{\text{Water.}}{2H_2O}$$

The delivery-tube, B, dips into mercury in the lower part of the vessel, C, containing water. This is necessary in order to prevent its being clogged by the gelatinous silica. As the gas passes into the water the following reaction occurs, viz.:

$$\underset{\text{Silicon Fluoride}}{3SiF_4} + \underset{\text{Water}}{4H_2O} = \underset{\text{Hydrofluosilicic Acid}}{2H_2SiF_6} + \underset{\text{Gelatinous Silica.}}{Si(OH)_4}$$

Silicon bromide, $SiBr_4$, and *silicon iodide*, SiI_4, exist. They are comparatively unimportant.

180. Silicon Dioxide, SiO_2, or **Silica, and Silicic Acid.**—Silicon dioxide is the only known oxide of silicon, and is an exceedingly important compound, existing not only in the mineral kingdom in huge deposits, but also in vegetables and animals. It occurs as a mineral, in a variety of forms, the most important of which is quartz, which occurs generally in crystals shaped as shown in Fig. 103. It also occurs in the amorphous state, as *opal*, *chalcedony*, *flint*, *agate*, and *jasper*.

Silicic acid has most probably the formula H_4SiO_4. It is unknown in a solid state, but may be obtained in solution as a clear, colorless liquid, with but feeble acid properties. It forms, as we have already seen, a large class of mineral substances, called silicates. The composition of many of these bodies is very complex, indicating the existence of a number of varieties of silicic acid.

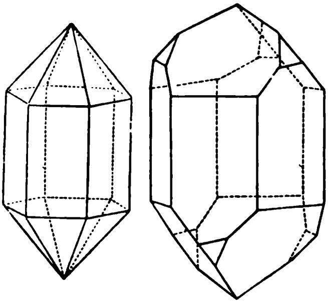


Fig. 103.
Crystals of Silicon Dioxide or Quartz.

If soluble glass, or potassium silicate, be thrown into a very dilute solution of hydrochloric acid in water, it will dissolve, and soluble silicic acid, hydrochloric acid, and sodium chloride will be found in the solution. The silicic acid is readily separated by the process known as *dialysis*, discovered by Graham.

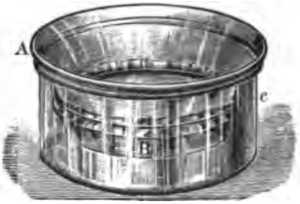


Fig. 104.—Graham's Dialyser.

Graham's dialyser, represented in Fig. 104, is employed to separate crystallizable substances, or *crystalloids*, from non-crystallizable substances, or *colloids*, such as jellies, glues, etc. The dialyser consists of a flat dish, A, Fig. 104, covered with a sheet of artificial parchment, B (paper steeped in sulphuric acid). If a mixture of crystalloids and colloids be placed in this dish, and the dish be floated in water in the vessel *c*, the crystalloids will pass through the parchment into the water, leaving the colloids in the vessel A.

If, then, the mixture of silicic acid, hydrochloric acid, and sodium chloride, be placed in the dish, silicic acid, being a colloid, remains in the vessel A, while the hydrochloric acid and the salt, which are crystalloids, pass into the water in *c*.

181. The Manufacture of Glass.—Silica is extensively employed in the arts in the manufacture of glass, which, in reality, is a mere mixture of different insoluble silicates with an excess of silica.

Glass is manufactured as follows: Pure sand is mixed with potassium or sodium carbonate, together with slaked lime, or red lead. When the mass is fused, combination ensues and carbonic acid is given off. The melted mass finally becomes clear and free from bubbles, and is then allowed to cool until it is ready for working.

The following are the principal varieties of glass, viz.: *Crown, and plate glass,* containing silica with an alkali and lime; *flint glass,* containing an excess of lead, which increases its density and renders it highly refractive; and *common bottle glass,* which is of a dark green color, and contains iron, lime, aluminium, and sodium.

Colored glasses are obtained by means of the addition of various metallic oxides; blue is obtained by the use of oxide of cobalt; emerald green, by the oxide of chromium; green, by black oxide of copper; intense ruby red, by the suboxide of copper; yellow, by oxide of uranium, oxide of silver, or oxide of antimony; and a whitish enamel, by oxide of tin.

Achromatic lenses are made of combinations of lenses formed of flint and of crown glass.

* * *

SYLLABUS.

Carbon is widely distributed in nature, both free and in combination. It forms an essential element in both plants and animals.

Carbon exists in three well marked allotropic modifications, viz., the diamond, graphite, and amorphous carbon.

The diamond is pure crystallized carbon. It occurs of various colors, but is generally colorless. It is the hardest of known substances; is a non-conductor of heat and electricity, and is highly refracting.

Graphite, or plumbago, is another variety of pure crystallized carbon. It is the substance used in ordinary lead-pencils. Graphite is very soft, and conducts both heat and electricity. It may be prepared artificially by the action of prolonged heat on ordinary carbon.

Graphite is used as a lubricant, and is also employed by electrotypers to coat the surfaces of their moulds in order to render them conductors of electricity.

The following are the principal varieties of amorphous carbon, viz.: lamp-black, gas-retort carbon, coke, wood charcoal, animal charcoal, and the different varieties of coal.

Lamp-black is produced by the incomplete combustion of substances rich in carbon.

Gas-retort carbon is the deposit that occurs in gas retorts, from the decomposition of a hydrocarbon gas or vapor by the heated walls of the retort.

Coke is the residue from a bituminous coal that is heated in the absence of air.

Wood charcoal results from heating wood out of contact with air.

Animal charcoal results from heating animal substances out of contact with air.

Charcoal possesses, in a very high degree, the property of absorbing various gases and vapors, and even of separating substances in solution.

Coal results from the decomposition of vegetable substances under water, in the presence of moderate heat and pressure. Its varieties are bituminous, semi-bituminous, and anthracite.

Carbon is very insoluble. It possesses an extremely powerful affinity for oxygen, for which reason it is largely employed as a reducing agent. There are two oxides of carbon; viz., the monoxide and the dioxide.

Carbon monoxide is formed when carbonic acid passes over heated carbon. The blue flame seen on the surface of a hard-coal fire is due to this cause.

Carbon monoxide is an exceedingly poisonous, colorless, and tasteless gas, with a faint but peculiar odor.

Carbon dioxide is one of the constituents of the atmosphere. It occurs, dissolved, in nearly all drinking-water; and, in the shape of carbonates, occurs in immense mineral deposits. It may be easily prepared by the action of hydrochloric acid on limestone.

Carbon dioxide is a colorless gas, that possesses a pungent smell and slightly acid taste. It supports neither combustion nor respiration. It is liquefied by cold and pressure.

Carbon disulphide is obtained by passing sulphur vapor over incandescent carbon. It is a poisonous, colorless, highly refracting, mobile liquid, possessing a peculiar, characteristic odor. It is largely employed in the arts for the extraction of oils and fats, and for the solution of india-rubber.

Carbon combines with hydrogen and forms a great number of compounds, called hydro-carbons. They are all volatile and combustible.

Combustion, as it ordinarily occurs, consists in the union of oxygen with the combustible body. The principal combustible materials are hydrogen and carbon. When insufficient oxygen is supplied to a burning body the hydrogen takes the oxygen; and the carbon being incompletely burned, causes the flame to smoke.

The cause of the heat developed by a burning body, is the falling of its atoms towards the oxygen or other atoms, with which it combines.

Flame is caused by the combustion of gaseous substances.

The rapidity of combustion is greatly increased by finely dividing the combustible body.

Three well-marked cones may be observed in an ordinary candle-flame, viz.: a dark central cone, consisting of unignited gases; an enveloping luminous cone, consisting of incompletely burned gases; and a non-luminous outer cone, consisting of completely burned gases. The second is sometimes called the reducing cone, and the third the oxidizing cone.

The Davy safety-lamp consists of an ordinary oil-lamp surrounded by fine wire gauze. When carried into an atmosphere of inflammable gas, the inflammable gas burns inside the lamp, but not outside it, because the gauze carries off the heat so rapidly that it cannot become hot enough to ignite the outside gas.

Illuminating gas is produced by the action of heat on coal contained in a vessel protected from the atmosphere. Before being fit for use it is purified from tar, ammonia, and various sulphur compounds, which it contains.

Silicon does not occur in a pure state in nature; but in the form of silicon dioxide and silicic acid it occurs in very great abundance, forming, as it does, about one-fourth, by weight, of the earth's crust.

Silicon may be obtained both in the amorphous and in the crystalline condition. With hydrogen, it forms silicon hydride, a spontaneously inflammable gas, possessing many of the properties of hydrogen phosphide.

Silicon fluoride is obtained by the action of strong sulphuric acid on fluor-spar and sand. When passed into water it is decomposed into hydro-fluo-silicic acid and gelatinous silica.

Silicon dioxide, or silica, occurs, in nature, either crystallized as quartz or its varieties; or amorphous, as opal, chalcedony, flint, agate, and jasper.

Silicic acid may be obtained in solution by dissolving soluble glass in water slightly acidulated with hydrochloric acid, and separating the resulting silicic acid by dialysis.

Dialysis is the process of separating crystalloids from colloids by placing them in a flat dish, provided with a bottom of artificial parchment, and floated in pure water.

Glass consists of a mixture of different insoluble silicates with excess of silica. It is manufactured by maintaining for a long time at the point of fusion mixtures of sand, potassium or sodium carbonate, and slaked lime or lead. Common flint glass contains an excess of lead; crown or plate glass contains an alkali and lime; common bottle glass contains iron, lime, aluminium, and sodium.

Various colors are imparted to glass by dissolving therein some metallic oxide.

QUESTIONS FOR REVIEW.

Describe the distribution of carbon in nature. In what different forms does carbon exist? Which of these are crystalline?

Name some of the physical properties of the diamond. How may the composition of the diamond be ascertained?

For what different purposes is the diamond employed?

Describe the physical properties of graphite or plumbago. How may graphite be produced artificially? For what different purposes is graphite employed in the arts?

Name the different varieties of amorphous carbon. How is lamp-black produced? For what purposes is it employed?

Explain the origin of gas-retort carbon.

Describe the manufacture of the carbon rods, or electrodes, employed in the electric arc light.

How is coke obtained? For what is it used?

Describe the method usually adopted for the production of charcoal. How is animal charcoal obtained?

Enumerate some of the properties of charcoal. To what property does charcoal owe its disinfecting powers?

Describe the origin of coal. Name some of the varieties of coal.

Describe some of the chemical properties of carbon. Why is carbon of so great use in the reduction of the metallic oxides?

What is the origin of the carbon monoxide seen burning on the surface of a hard-coal fire? How may carbon monoxide be obtained for use in the laboratory? Name some of its properties.

Name some of the natural sources of carbon dioxide.

To what does the poison valley of Java owe its dangerous character?

How may carbon dioxide be conveniently prepared? Name some of the properties of carbon dioxide.

Describe experiments by means of which any of these properties may be illustrated.

Upon what do most fire-extinguishers owe their power of extinguishing flame?

How is carbon disulphide obtained? What are its properties? For what different purposes is it employed in the arts?

What two properties are common to all the hydrocarbons?

What is the real nature of combustion? Why do certain bodies burn with smoky, sooty flames? Explain the cause of the heat developed by combustion.

What is meant by kinetic energy? What is meant by potential energy? Illustrate.

Why does the combustion of the same weight of different substances produce different amounts of heat?

Why is the rapidity of combustion increased by finely dividing the combustible body? How may this be demonstrated experimentally?

Explain the cause of flame. Of what three distinct portions does the flame of an ordinary candle consist? What properties do these parts possess?

How may it be shown that all candle-flames are hollow? Why should a candle-flame be hollow?

Describe the construction of the Davy safety-lamp. Why cannot the flame inside the gauze covering ignite the gases outside it? What are the probable causes of the occasional failure of the safety-lamp?

Describe the process employed for the manufacture and purification of illuminating gas.

In what different forms does silicon occur in nature? What proportion, by weight, of the earth's crust, is composed of silicon?

How may silicon be prepared? In what different forms does it occur?

How is silicon hydride formed? Describe some of its properties.

How is silicon fluoride prepared? How may hydrofluosilicic acid be obtained from it?

Name some of the different forms in which silicon dioxide, or silica, occurs in nature.

Describe Graham's process of dialysis. What use is made of this process for obtaining a solution of silicic acid?

Describe the construction of Graham's dialyser.

What is the composition of glass? How is glass manufactured?

What is the difference between crown glass and flint glass? For what purposes are these substances sometimes used?

What is the composition of ordinary bottle glass?

How are various colors imparted to glass? How is red glass obtained? green glass? blue glass?

THE METALS.

SECTION I.

INTRODUCTORY.

CHAPTER VIII.

PROPERTIES AND CLASSIFICATION OF THE METALS.

182. General Characteristics of the Metals.—The following general properties characterize the metals as a class, viz.: They possess a peculiar lustre, known as the metallic lustre; they are conductors of both heat and electricity; they generally have a high specific gravity; they are opaque, except when in the state of very thin films; some of them are malleable and ductile; they are all electro-positive, that is, appear at the negative electrode of a battery when one of their compounds is decomposed by the electric current, and as a rule their oxides are basic, except the higher oxides, which are sometimes acid. Nearly all the metals may be crystallized.

The metallic lustre is developed in the metals by rubbing or burnishing them. The metals are sometimes obtained in the form of metallic powders, so finely divided as to appear as dull powders. These, however, acquire a metallic lustre on rubbing with a hard body.

183. Hardness, Brittleness, and Tenacity.—The metals vary greatly in their hardness; some, like lead, being readily scratched with the finger-nail, or are even softer, as potassium or sodium, while others, like manganese and chromium, are hard enough to scratch glass.

They differ also in their brittleness and tenacity; some, like zinc, being readily broken by bending, while others, such as iron, copper, silver, and gold, require great force to break them.

The tenacity of a metal is measured by the force required to break it when drawn out into a wire of a given diameter.

The following are arranged in the order of their tenacity, beginning with the most tenacious, viz.: Iron, copper, platinum, silver, gold, zinc, nickel, tin, and lead.

184. Ductility and Malleability.—When sufficient pressure is exerted on them, metals flow like liquids.

A metal that can be drawn out into a wire is said to be ductile. The process of *wire* drawing consists in drawing the wire through holes in a hardened steel plate. The wire is drawn successively through holes that gradually decrease in diameter.

The apparatus employed is shown in Fig. 105. The wire wrapped on the drum, A, is reduced in diameter, and consequently increased in length, by being drawn through a hole of smaller diameter in the draw-plate, *f f*. The machine is driven by power applied at the pulley, P, which is transmitted to the drum, A, by gear-wheels, *g*, *g*, as shown in the figure.

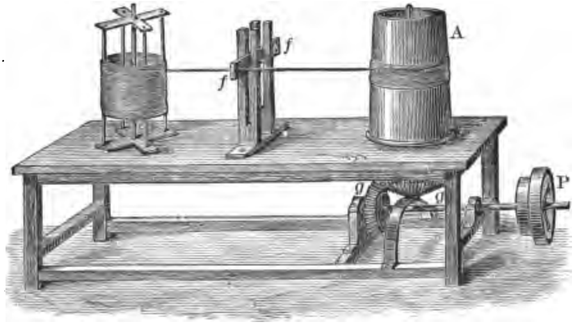


Fig. 105.—Wire-Drawing Apparatus.

The order of ductility of the more common metals is as follows, viz.: Gold, silver, platinum, aluminium, iron, nickel, copper, zinc, tin, and lead.

Metals that can readily be beaten or rolled out into thin sheets are said to be *malleable.* The order of malleability under the hammer is not quite the same as under the roller.

The following is the order of malleability, viz.: Gold, silver, aluminium, copper, tin, platinum, lead, zinc, iron, and nickel.

185. Specific Gravity.—The metals vary very considerably in their specific gravity—most, however, are heavier than water. The following table shows these differences:

Specific Gravity of the Metals.

Platinum (rolled)	23.	Cobalt (cast)	7.79
“ (cast)	21.15	Iron (malleable)	7.79
Osmium	21.40	“ (cast)	7.25
Gold (cast)	19.35	Tin (cast)	7.29
Mercury	13.59	Manganese	7.20
Palladium	11.80	Chromium	7.01
Lead (cast)	11.33	Zinc (cast)	6.86
Silver (cast)	10.57	Aluminium	2.56
Nickel	8.82	Sodium	0.97
Copper (cast)	8.79	Potassium	0.86
Cadmium	8.60	Lithium	0.59

186. Fusibility of the Metals.—The metals vary greatly in their fusibility, as will be seen by an inspection of the following table:

Fusibility of the Metals.

Mercury	—39°.2 F.	Zinc	773° F.
Rubidium	101°.3 “	Silver	1873° “
Potassium	144°.5 “	Copper	1996° “
Sodium	207°.7 “	Gold	2016° “
Lithium	356° “	Cast-iron	2786° “
Tin	442° “	Nickel (about)	2912° “
Cadmium	442° “	Cobalt (about)	2912° “
Bismuth	507° “	Platinum (about)	3632° “
Thallium	561° “	Iridium (about)	4532° “

187. Alloys and Amalgams.—The mixtures or combinations of metals with one another are called *alloys.* Alloys do not appear to be definite chemical compounds—at least, not in all cases, for some of the metals seem to alloy, or mix with one another, in nearly all proportions. Again, alloys, unlike most chemical compounds, often partake strongly of the properties of their constituents. Their point of fusion is always lower than that of any of their constituents.

The following gives the composition of some of the more important alloys, viz.:

Solder (plumbers')—Tin 66, Lead 34 parts.
Pewter (hard)—Tin 92, Lead 8 parts.
Britannia Metal—Tin 100, Antimony 8, Copper 4, Bismuth 1 part.
German Silver—Copper 50, Zinc 25, Nickel 25 parts.
Type-metal—Lead 80, Antimony 20 "
Brass (white)—Copper 65, Zinc 35 "
" (red) " 90, " 10 "
Speculum Metal—Tin 33, Copper 67 "
Bell-metal " 22, " 78 "
Gun-metal " 10, " 100 "
Aluminium Bronze—Aluminium 10, Copper 90 "

Compounds or mixtures of metals with mercury are called *amalgams.*

188. Extraction of the Metals from their Ores.—Those metals that do not occur in nature in a pure state, as do gold, silver, copper, etc., generally occur either as oxides, sulphides, chlorides, or in combination with various acids, such as carbonic, sulphuric, phosphoric, silicic, etc.

The mode of extracting the metal, though dependent on the particular case, may be indicated in general as follows:

Oxides are generally reduced by being heated with charcoal, out of contact with air.

Sulphides are roasted in the air, by means of which the sulphur is driven off and the metal oxidized. The oxides are then reduced by carbon.

189. Fracture of the Metals.—Many of the metallic bodies possess a characteristic fracture, dependent to a great extent on their crystalline, or their amorphous condition. These fractures are important as indicating in many instances the degree of purity of the metal, or some physical peculiarity possessed by it. They are as follows, viz.:

1st. *Conchoidal fracture*, in which the broken surfaces are concave and convex, that is, have rounded elevations and depressions.

2d. *Columnar fracture*, in which the broken surfaces show a columnar texture, as in tin.

3d. *Fibrous fracture*, in which the broken surfaces show a fibrous structure, as in a bar of wrought-iron. This fracture is said to be *silky*, when the fibres are fine and glossy, as in tough copper.

4th. *Crystalline fracture*, in which the broken surfaces show the faces of crystals, as in antimony and zinc.

5th. *Granular fracture*, in which the broken surfaces present the appearance of fine granules, as in some varieties of iron.

190. Classification of the Metals.—It is difficult to make a complete classification of the metals based on their quantivalence, since in many instances this is uncertain. The fact that all the non-metals form volatile compounds with hydrogen, renders the determination of their quantivalence comparatively simple. The metals, however, do not form volatile compounds with hydrogen. Their quantivalence is, therefore, determined from their compounds with some of the monad alcohol radicals, or better still, with chlorine. The chlorides are all volatile, but some of them only at such high temperatures as to render the determination of their vapor densities impracticable. In the following classification, therefore, it will be understood that the valency is in many instances uncertain.

191. The Perissad Metals.—

MONADS.

Metals of the Alkalies and Silver.

1. Potassium.
2. Sodium.
3. Lithium.
4. Cæsium.
5. Rubidium.
6. Silver.

TRIADS.

1. Gold.
2. Thallium.

PENTADS.

1. Vanadium.
2. Niobium or Columbium.
3. Tantalum.

192. The Artiad Metals.—

DYADS.

Group I.—*Metals of the Alkaline Earths.*

1. Barium.
2. Strontium.
3. Calcium.
4. Lead.

Group II.—*Metals of the Earths.*

1. Aluminium.
2. Glucinum or Beryllium.
3. Thorium.
4. Yttrium.
5. Erbium.
6. Terbium.
7. Cerium.
8. Lanthanum.
9. Didymium.
10. Zirconium.

Group III.—*Metals of the Magnesium Group.*

1. Magnesium.
2. Zinc.
3. Cadmium.

Group IV.—*Metals of the Mercury Group.*

1. Mercury.
2. Copper.

TETRADS.

Group I.—*Metals of the Platinum Group.*

1. Platinum.
2. Palladium.
3. Iridium.
4. Rhodium.
5. Ruthenium.
6. Osmium.

Group II.—*Metals of the Tin Group.*

1. Tin.
2. Titanium.

HEXADS?

Group I.—*Metals of the Iron Group.*

1. Iron.
2. Manganese.
3. Cobalt.
4. Nickel.
5. Indium.
6. Gallium.

Group II.—*Metals of the Chromium Group.*

1. Chromium.
2. Molybdenum.
3. Tungsten, or Wolframium.
4. Uranium.

SYLLABUS.

Metallic substances possess a peculiar lustre called the metallic lustre.

All the metals conduct both heat and electricity, though to very different degrees. They are all electro-positive, and all their oxides, except the higher oxides, are basic.

Metallic substances sometimes occur in the state of dull powders, which do not exhibit metallic lustre until rubbed or burnished.

Metallic substances vary considerably in their hardness; some are easily scratched, while others are sufficiently hard to scratch glass. They differ also in their brittleness; some are readily broken into pieces, while others are exceedingly tough.

Some metallic substances require a very great force to break them when drawn out in the form of a rod or wire, that is to say, they are very tenacious; others have but little tenacity. Iron, copper, and platinum are very tenacious.

A metal is malleable, if it can be beaten or rolled out into thin leaves; it is ductile, if it can be drawn out into thin wire. Gold, silver, aluminium, and copper are very malleable. Gold, silver, and platinum are very ductile.

Most of the metals have a higher specific gravity than water, some of them being more than twenty times heavier than water. Sodium, potassium, and lithium, however, are lighter than water.

The metals vary widely in their fusibility. Some, like rubidium, potassium, and sodium, melt at temperatures lower than the boiling-point of water; while others require the highest heat of a blast furnace to fuse them.

Mixtures, or combinations of metals with one another, are called alloys. Compounds or mixtures with mercury are called amalgams.

Speculum metal, bell metal, and gun metal are alloys of copper and tin. Brass is an alloy of copper and zinc. German silver is an alloy of copper, zinc, and antimony.

The principal metallic ores are oxides, sulphides, chlorides, or salts of the metals.

The oxides are reduced by heating with charcoal out of contact with air. The sulphides are first roasted in free air, which drives off the sulphur and converts the metals into oxides, and the oxides are subsequently reduced by charcoal.

The metals are partly characterized by their fracture, which may be conchoidal, columnar, fibrous, silky, crystalline, or granular.

Since some of the metals do not readily form volatile compounds, their valency is not certainly known.

QUESTIONS FOR REVIEW.

Name some of the properties that serve to distinguish the metals as a class. Are these properties possessed by all of the metals to the same degree?

Are the metals as a class crystallizable, or amorphous?

Define hardness, brittleness, tenacity. Give some examples of each.

Define ductility. Name some of the metals in the order of their ductility. Describe the process of wire-drawing.

Define malleability. Are the metals equally malleable under the hammer and the roller? Name some of the metals in the order of their malleability.

Name some of the metals whose specific gravity is more than twenty times greater than that of water. Name some whose specific gravity is between ten and twenty times greater than water. Name some whose specific gravity is less than that of water.

Name some of the readily fusible metals. Name some of the difficultly fusible metals.

Which fuses the more readily, lead or zinc? Iron or copper? Silver or gold?

Define alloys; amalgams. Are alloys definite chemical compounds?

What peculiarity is there concerning the temperature of fusibility of alloys as compared with that of their components?

What metals enter into the composition of bell-metal; plumbers' solder; type-metal; and brass?

In what different forms do most of the metallic ores occur?

Describe the process of extracting a metal from its oxide. Describe the process of extracting it from its sulphide. Of what two distinct steps does this process consist?

Describe some of the characteristic fractures of the metals.

What difficulty is there in arranging the metals into classes according to their quantivalence?

Into what two classes may all the metals be divided?

THE PERISSAD METALS.

SECTION II.

THE MONAD METALS.

Metals of the Alkalies and Silver.

1. Potassium.	4. Cæsium.
2. Sodium.	5. Rubidium.
3. Lithium.	6. Silver.

CHAPTER IX.

THE METALS OF THE ALKALIES AND SILVER.

193. Characteristics of the Group.—The word alkali was originally applied to a soda salt obtained from the ashes of certain sea plants, but was gradually extended to other bodies possessing similar properties. The alkalies have a caustic taste, turn an infusion of blue cabbage green, and turmeric solution from yellow to brown. Their lower oxides combine with acids and neutralize them, and are powerful bases.

The alkalies were regarded as elementary substances until as late as 1807, when Davy, by the aid of a powerful voltaic battery, decomposed them and obtained the metals potassium, sodium, etc.

The metals of this class are all soft, readily fusible, and are volatile at sufficiently high temperatures. They have an energetic attraction for oxygen, even decomposing water in order to obtain it. They form deliquescent basic oxides, which have a powerful affinity for water, and when hydrated are powerfully caustic. The compound radical ammonium, NH_4, has the properties of an alkaline metal, and may be considered as belonging to this group.

POTASSIUM.

K = 39.1. Specific gravity = 0.865. Molecular weight = 78.2. Quantivalence = I., III., V. Free molecules, K—K. Discovered by Davy in 1807.

194. Occurrence and Preparation.—Potassium occurs in nature in combination only. It is very widely distributed, and is an essential ingredient of many minerals. It occurs in all fertile soils, and is found in all plants and in animals.

Metallic potassium is obtained in the arts by the action of a white heat on a mixture of potassium carbonate and charcoal. The following reaction occurs, viz.:

$$\underset{\text{Potassium Carbonate}}{K_2CO_3} + \underset{\text{Carbon}}{2C} = \underset{\text{Potassium}}{K_2} + \underset{\text{Carbon Monoxide.}}{3CO}$$

The potassium is given off as a vapor, which is condensed in suitably shaped vessels.

The manufacture of potassium is attended with considerable danger, owing to the formation of a black compound which is exceedingly explosive. Its formation may, however, be avoided by rapidly condensing the potassium vapor as fast as it is formed.

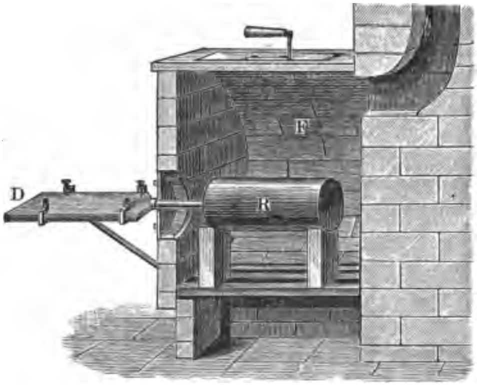


Fig. 106.—Preparation of Potassium.

The apparatus employed is shown in Fig. 106. The iron retort, R, which in practice is covered with clay, is placed in the furnace, F, and provided with means for connection with the flat condenser, D, formed of two pieces of iron clamped together. An opening in D allows the condensed, liquid potassium to drop into a receiver filled with naphtha.

195. Properties of Potassium.—Potassium is a very soft, bluish-white metal, that at 32° F. has a crystalline fracture. It melts at a temperature considerably below the boiling-point of water, and, at a high temperature, boils and emits a green vapor.

Potassium possesses an exceedingly energetic attraction for oxygen. It is rapidly oxidized when exposed to air, and must, therefore, be kept in some liquid like naphtha, that contains no oxygen. Thrown on water, it floats, decomposing the water and liberating its hydrogen, which igniting burns with the characteristic violet flame of potassium. Its great affinity for oxygen renders it a powerful reducing agent.

196. Potassium Hydrate.—There are two oxides of potassium, viz., K_2O, potassium monoxide, which is powerfully basic, and K_2O_4, which is unimportant. Potassium monoxide is formed when potassium oxidizes in dry air. When thrown into water it violently combines with it, forming potassium hydrate, KOH; thus,

$$\underset{\text{Potassium Monoxide}}{K_2O} + \underset{\text{Water}}{H_2O} = \underset{\text{Potassium Hydrate.}}{2KOH}$$

Potassium hydrate is a basic hydrate, in which one of the hydrogen atoms in the water molecule is replaced by potassium.

Potassium hydrate is prepared commercially by boiling a mixture of potassium carbonate, water, and milk of lime (calcium hydrate). The reaction is as follows, viz.:

$$\underset{\substack{\text{Potassium}\\\text{Carbonate}}}{K_2CO_3} + \underset{\substack{\text{Calcium}\\\text{Hydrate}}}{Ca(OH)_2} = \underset{\substack{\text{Calcium}\\\text{Carbonate}}}{CaCO_3} + \underset{\substack{\text{Potassium}\\\text{Hydrate.}}}{2KOH}$$

The filtered liquid is rapidly evaporated, and the residue fused, and cast in cylindrical sticks. Thus prepared it generally contains lime and other impurities, from which it may be separated by dissolving in alcohol, decanting the solution and evaporating the clear liquid to dryness.

Potassium hydrate is commonly known as caustic potash. It is a hard, brittle, white solid, that rapidly deliquesces on exposure to the air, and is powerfully caustic, rapidly softening and destroying the skin; hence its use in surgery. Potash lye is an aqueous solution of the hydrate. It is used largely in the manufacture of soft soap.

197. Compounds of Potassium with Sulphur and the Haloids.—Potassium forms with sulphur five compounds, viz., K_2S, K_2S_2, K_2S_3, K_2S_4, and K_2S_5. They are comparatively unimportant.

Potassium chloride, KCl, somewhat resembles common salt, having a similar taste and crystallizing in cubes.

Potassium iodide, KI, and *Potassium Bromide*, KBr, are prepared by adding iodine and bromine, respectively, to a solution of potassium hydrate, and evaporating to dryness. The residue, which contains both the iodide and iodate, or the bromide and bromate, is then heated to redness, by which the entire mass is reduced to the iodide or the bromide. The iodide and bromide are both white salts, that crystallize in cubes. They are extensively employed as medicines.

Potassium fluoride, KF, also crystallizes in cubes.

198. Potassium Nitrate, KNO_3, or *Saltpetre*, occurs native as an efflorescence in the soils of hot, dry countries. Its formation, as we have already seen, is due to the decomposition of organic matters in the presence of an alkali. The native salt is purified by solution in water and crystallization.

Potassium nitrate is also prepared from sodium nitrate by adding the latter to a boiling solution of potassium carbonate, or by decomposing it by potassium chloride.

Potassium nitrate is dimorphous, crystallizing in rhombic prisms and in rhombohedrons. It has a slightly bitter, cooling taste, and is very soluble in hot water. It is employed in large quantities in the manufacture of gunpowder. It is also employed in pickling meat, imparting to it a red color.

Gunpowder is made by the intimate mixture of nitre, charcoal, and sulphur, in nearly the proportion of two molecules of nitre, three atoms of carbon, and one atom of sulphur. These proportions vary somewhat in different kinds of powder. The ingredients are finely divided, and when mixed with water thoroughly ground together. The resulting mass is subjected to great pressure, and the cake so formed carefully broken into fragments. Gunpowder owes its explosive powers to the large volume of gases produced by its combustion.

Nearly all fire-works contain potassium nitrate and charcoal.

199. Potassium Sulphates, and Potassium Chlorate.—*Potassium sulphate*, K_2SO_4, is a by-product in various chemical operations. It crystallizes in modified rhombic prisms, Fig. 107, that are but slightly soluble in water, and are anhydrous.

Potassium acid sulphate, $KHSO_4$, is formed by adding strong sulphuric acid to the preceding. It is more soluble in water than the potassium sulphate.

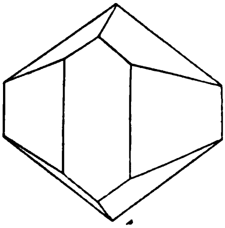


Fig. 107.—Potassium Sulphate.

Potassium chlorate, $KClO_3$, is formed by passing chlorine through a concentrated solution of potassium hydrate. Thus:

$$\underset{\text{Chlorine}}{6Cl} + \underset{\substack{\text{Potassium}\\\text{Hydrate}}}{6KOH} = \underset{\substack{\text{Potassium}\\\text{Chlorate}}}{KClO_3} + \underset{\substack{\text{Potassium}\\\text{Chloride}}}{5KCl} + \underset{\text{Water.}}{3H_2O}$$

Potassium chlorate crystallizes in white, rhomboidal tables. It is largely employed as a source of oxygen, which it readily yields on being heated, and is used in small quantities as a medicine, especially in inflammation of the throat. It possesses powerful oxidizing properties, and is poisonous.

Experiment 57.—Pass some chlorine through a wide delivery-tube into a concentrated solution of potassium hydrate contained in a beaker. In a short time, sparkling crystals of potassium chlorate will appear.

Experiment 58.—Mix together equal parts of powdered potassium chlorate and common sugar. Touch the mixture with a glass rod that has been dipped into sulphuric acid, and a violent deflagration will follow.

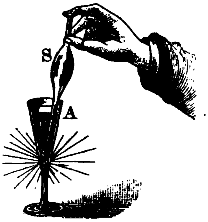


Fig. 108.—Combustion of Phosphorus under Water.

Experiment 59.—Place a small fragment of phosphorus in the bottom of a suitable vessel, A, Fig. 108, filled with water, and throw into it a few crystals of potassium chlorate. Then pour some sulphuric acid through the pipette or drop-tube, S, and a brilliant combustion of the phosphorus will take place under water. In this and the preceding experiment, chlorine tetroxide is liberated, and causes the combustion.

Experiment 60.—Reduce a small crystal of potassium chlorate to a fine powder, and carefully mix it with about one-half its weight of flowers of sulphur. Lay the mixture on an anvil, and strike it a sharp blow with a hammer; it will explode violently. Use a very small quantity, and mix with the fingers.

200. Potassium Carbonates.—There are two carbonates, viz.: the neutral and the acid.

Potassium neutral carbonate, K_2CO_3, known in commerce as *potash,* is obtained from the ashes of plants; the ashes are boiled in pots, hence the name. An important source of this salt is found in a product obtained during the manufacture of beet-sugar. The wool of sheep also contains a large quantity of this salt, derived from the sweat of the animals.

It is a white, granular powder, that deliquesces on exposure to the air, and is very soluble in water. It is largely used in the manufacture of soft soaps and glass.

Potassium acid carbonate, $KHCO_3$, is formed when carbonic acid gas is passed through a solution of the neutral carbonate. It crystallizes in large, transparent crystals that are less soluble in water than the neutral carbonate.

201. Tests for Potassium.—Potash imparts a violet tint to flame. It forms no precipitate with hydrogen sulphide or ammonium sulphide, but gives a white, gelatinous precipitate with hydrofluosilicic acid, and a yellow crystalline precipitate with platinum tetrachloride.

SODIUM.

Na = 23. Specific gravity = 0.97. Molecular weight = 46. Quantivalence = I., III. Free molecule, Na—Na. Discovered by Davy in 1807.

202. Occurrence, Preparation, and Properties.—Sodium occurs widely diffused in nature. Its principal sources are in the vast deposits of sodium chloride that occur in different geological formations in various parts of the world, in the water of the ocean, and of inland lakes and seas; as deposits of sodium nitrate, carbonate and sulphate, and in various minerals.

Metallic sodium is obtained commercially by heating to a white heat a mixture of sodium carbonate and charcoal with a little chalk, in cast-iron retorts, similar to those employed in the manufacture of potassium. The manufacture is easier than that of potassium, and is not liable to danger from explosion. Large quantities of sodium are used in the preparation of aluminium.

Metallic sodium has a silvery-white lustre, and resembles potassium both in appearance and properties. It fuses at 207°.7 F., and burns in the air with a bright yellow flame. It has a strong affinity for oxygen, and will decompose water when thrown on it, but will not ignite the liberated hydrogen unless the water be previously warmed. It volatilizes less readily than potassium, forming a vapor that is colorless in small bulk, but purple in larger quantities.

Fig. 109.
Combustion of Sodium.

203. Sodium Oxides and Hydrate.—Sodium forms two oxides, viz., *sodium monoxide*, Na_2O, which is a powerful base, and *sodium peroxide*, Na_2O_2, which is unimportant.

Sodium hydrate, or *caustic soda*, NaOH, is formed by adding the monoxide to water, with which it vigorously combines. It is also formed when sodium is thrown on water.

Caustic soda is prepared commercially by the action of lime on sodium carbonate, in the same manner as in the preparation of caustic potash. It may be obtained in the form of an opaque, brittle solid, that deliquesces rapidly on exposure to the air, and is a powerful cautery. The commercial name of caustic soda is concentrated lye. It is extensively employed in the manufacture of soap.

204. Sodium Chloride, NaCl, or Common Salt.—This important substance occurs in vast deposits of rock salt, or is obtained from the waters of shallow arms of the sea, or from the waters of salt springs by evaporation. The rock salt is either mined directly, or borings are made into the deposits, and water run into the borings and pumped out when thoroughly charged with the salt.

Sodium chloride crystallizes in cubes, which sometimes assume a curious hopper shape. A cube, *a*, Fig. 110, forms, which floats in the liquid with its upper surface a little below the general level; other cubes are deposited on the edges of this, and the mass thus formed again sinks and receives fresh layers, finally forming the large mass shown in the figure at B.

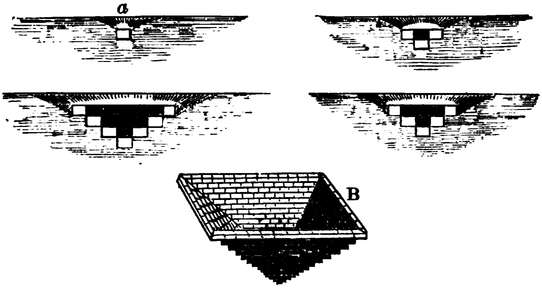


Fig. 110.—Crystals of Common Salt.

Sodium chloride possesses a well-known, pleasant saline taste. It is necessary to the life of animals; for, when deprived of it for any considerable time they die. It is readily soluble in water.

Sodium chloride is used for packing and preserving meats and for a glaze for earthenware.

205. Sodium Carbonate, Na_2CO_3, or Soda, or Sal Soda, was formerly obtained from the ashes of sea plants, but is now prepared from sodium chloride by a process called the Leblanc process, from the name of its inventor. The process consists of three distinct steps, viz.:

1st. The conversion of the sodium chloride into sodium sulphate. The hydrochloric acid gas so liberated is led into water and forms an important source of commercial hydrochloric acid.

2d. The decomposition of the sodium sulphate, by mixing it with chalk and coal, and exposing it to intense heat in suitably contrived furnaces. A mixture of soluble sodium carbonate and insoluble calcium monosulphide is thus produced. Thus:

$$\begin{array}{ccccccccccc} Na_2SO_4 & + & CaCO_3 & + & 4C & = & Na_2CO_3 & + & CaS & + & 4CO \\ \begin{array}{c}\text{Sodium}\\ \text{Sulphate}\end{array} & + & \begin{array}{c}\text{Calcium}\\ \text{Carbonate}\end{array} & + & \text{Carbon} & = & \begin{array}{c}\text{Sodium}\\ \text{Carbonate}\end{array} & + & \begin{array}{c}\text{Calcium}\\ \text{Sulphide}\end{array} & + & \begin{array}{c}\text{Carbon}\\ \text{Monoxide.}\end{array} \end{array}$$

3d. The treatment with water of the mass produced by the preceding process and the crystallization of the soluble carbonate.

The furnace for the decomposition of the sulphate is shown in Fig. 111. The flame plays over the mixture. The decomposition occurs in the compartment A, nearer the fire. The mass in B is merely dried by the heat. When the charge in A is rendered pasty by the heat, it is raked out and forms what is known technically as *ball soda* or *black ash*. The dried charge in B is now transferred to A and the fresh charge placed in B. The black ash is treated with water,

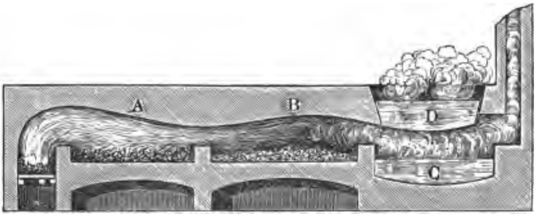


Fig. 111.—Furnace for Decomposition of Sodium Sulphate.

which dissolves the soluble carbonate, and the solution is concentrated in the chamber D, and finally evaporated to dryness in the chamber C.

Sodium carbonate is also prepared by heating the mineral cryolite, a double fluoride of sodium and aluminium, with lime.

Sodium carbonate can be obtained in transparent, oblique rhombic crystals, that contain ten molecules of water of crystallization. These crystals effloresce on exposure to the air, and when heated fuse in their water of crystallization.

Sodium carbonate is used in large quantities for the manufacture of soap and glass. It is also employed in washing and in calico printing.

Sodium bicarbonate, $2HNaCO_3 + 9H_2O$, is prepared by the action of carbonic acid gas on the carbonate. It is extensively used for the manufacture of effervescing drinks, for baking powders, and in medicine.

206. Other Salts of Sodium.—There are two sulphates, viz., *sodium neutral sulphate*, Na_2SO_4, and *sodium acid sulphate*, $NaHSO_4$. The former is obtained from the mother liquor remaining after the crystallization of sodium chloride from evaporated sea-water. The sodium acid sulphate is obtained by the addition of sulphuric acid to the neutral sulphate. It is more soluble in water than the former.

Borax, or *Sodium Pyroborate*, $Na_2Bo_4O_7 + 10H_2O$, occurs native as *tincal*. Borax is used as a flux in the welding of metals. The borax, by its property of dissolving the oxides that form on the metals, cleanses their surfaces, and thus enables them to cohere. It is extensively employed in blowpipe analysis.

Sodium Phosphates.—Sodium forms salts with all the phosphoric acids.

Sodium tetrasilicate, $Na_2Si_4O_9$, or soluble glass, is obtained by heating a mixture of sand, soda-ash, and charcoal. It is used as a cement, for fixing colors in fresco paintings, and in the manufacture of artificial stone.

Sodium nitrate, $NaNO_3$, occurs native in Chili, Peru, and other localities. It is largely used in the manufacture of nitric acid.

207. Detection of Sodium Salts.—One of the most characteristic tests for sodium is the yellow color its salts impart to an otherwise colorless flame.

Experiment 61.—Soak a bit of lampwick in a solution of common salt. Place it in a saucer and pour some alcohol over it. On lighting the alcohol, it will burn with a peculiar yellow flame. This flame contains only yellow light, and if colored fabrics be examined by its light in an otherwise darkened room, very curious effects will be produced. The face, too, loses all its red tints and assumes the ashen hue of death.

* * *

LITHIUM.

Li = 7. Specific gravity = 0.59. Discovered by Arfvedson, in 1817.

208. Sources and Properties—Characteristics of Lithium Salts.—Lithium is a rare metal that occurs in certain minerals, especially in lepidolite or lithia mica. It also occurs in small quantities, widely distributed, in the waters of certain springs, and in many plants and animals.

Lithium may be readily obtained in the metallic state by the action of an electrical current on fused lithium chloride.

Metallic lithium has a silvery lustre, and, like the other alkaline metals, tarnishes on exposure to the air, though less readily than potassium or sodium. It is the lightest solid known, its specific gravity being only 0.59. It is very soft, and marks paper like lead. It melts at 356° F. When thrown on water it floats about and decomposes it like sodium, but does not ignite the evolved hydrogen.

The salts of lithium are very fusible, and have the characteristic property of imparting a brilliant crimson tint to an otherwise colorless flame. This flame, when examined by the spectroscope, gives a characteristic spectrum. Quantities smaller than the one ten-millionth of a grain can be easily detected.

When any chemical substance is heated to incandescence in such a manner as to give its molecules great freedom of motion, that is, when its vapor is rendered luminous, it emits a light of a perfectly characteristic color. This light generally contains a number of different colors, and as the eye cannot distinguish them when together, they are passed through one or more prisms, and examined through a telescope. Such an instrument is called a *spectroscope*, and is of great service in chemical analysis.

CÆSIUM AND RUBIDIUM.

Cs = 133. Sp. Gr. = ? Discovered by Bunsen and Kirchoff in 1860.
Rb = 85.2. Sp. Gr. = 1.52. Discovered by Bunsen and Kirchoff in 1861.

209. Sources and Properties—Characteristics of Cæsium and Rubidium Salts.—Cæsium and rubidium are very rare elements, that were discovered by Bunsen and Kirchoff by means of the spectroscope. Like lithium, they are widely diffused in nature, though in exceedingly small quantities. They both give blue lines, but in different parts of the spectrum. They are generally obtained from the waters of certain springs, and in the mineral lepidolite. Metallic rubidium is of a silver-white color, and melts at a low temperature, emitting a bluish vapor. Cæsium has not yet been obtained in the metallic state. These elements are among the most electropositive metals known.

The salts of cæsium and rubidium are very similar to those of potash, and cannot be distinguished from them by ordinary reagents. Their hydrates form powerful bases.

SILVER.

Ag = 108. Sp. Gr. = 10.57. Quantivalence = I., III.

210. Occurrence in Nature and Extraction.—Though silver differs widely from the metals of the alkalies in physical and chemical properties, yet it appears to be of the same quantivalence, and is isomeric with them, forming a silver alum similar in form to common potash alum.

Silver occurs in nature both native or pure, and in combination. Its principal ores are sulphides and chlorides, either pure or in combination with copper, arsenic, and antimony.

Silver is obtained from its ores in one of three different ways, viz.:

1st. By alloying it with lead, and then removing the lead by oxidation.

2d. By amalgamation with mercury, the latter being afterwards driven off by heat.

3d. By converting it into a soluble salt, and then precipitating the silver by means of metallic copper.

A very important source of silver is the ore of lead, called galena, which generally contains a trace of silver, often sufficient in amount to pay for extraction. This silver all remains in the lead after the latter is reduced to the metallic state. To obtain the silver, it was formerly customary to remove all the lead by oxidation, but it was fortunately discovered that when lead is melted and allowed to slowly cool, pure lead solidifies first, and the part that momentarily remains in a liquid state contains nearly all the silver. This portion only is submitted to the oxidizing or the *cupellation* process.

The cupellation process consists essentially in melting the lead in a shallow oval basin, called a *cupel*, made from a mixture of bone and wood ashes. The cupel is placed in a furnace, and the lead removed by a continuous blast of air driven over its surface. Oxide of lead is formed, part of which is absorbed by the porous cupel. The process is completed when the melted mass is no longer covered with oxide, but presents a bright, metallic surface.

The Amalgamation Process.—In this process the ore is roasted with common salt, by which the silver is converted into a chloride. The washed ore is ground and placed in

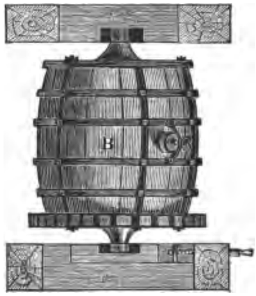


Fig. 112.
Amalgamation Process.

a barrel, B, Fig. 112, with scraps of iron and mercury. The iron reduces the silver to the metallic state; it is then dissolved by the mercury, from which it is afterwards separated by distillation.

211. Properties of Silver.—Metallic silver has an exceedingly white color and high metallic lustre. It is very malleable and ductile, and possesses high conducting powers for both heat and electricity. It is not oxidized on long exposure to the air and moisture. When melted it possesses the curious power of absorbing oxygen to the extent of some twenty-two times its volume. On cooling this is expelled, sometimes violently, scattering some of the molten metal, or, as it is called, *spitting*. Added in small quantities to glass, it imparts to it a yellow color. In the presence of hydrogen sulphide it rapidly tarnishes, becoming covered with a film of silver sulphide.

212. The Assaying of Silver.—Pure silver is too soft to be directly used for coin, jewelry, or plate, and for these purposes is hardened by being mixed with a small quantity of copper. The quantity of copper varies from 7 to 25 per cent. In order to readily ascertain the properties of the comparatively worthless metal present in a given alloy, two methods of assaying are adopted, viz., the *dry* assay, or the method of cupellation, and the *wet* assay.

In the dry assay a weighed quantity of the alloy is added to melted lead in a cupel and the copper and lead removed by oxidation. The remaining button of silver is then carefully weighed.

In the wet assay a known weight of the alloy is dissolved in nitric acid; then a standard solution of common salt, that is, a solution containing a known amount of salt, is carefully added to the solution, until it will no longer give a milky-white precipitate of silver chloride. The amount of silver is then readily calculated from the amount of the solution employed.

213. Compounds of Silver with Oxygen, Chlorine, Iodine,

and Bromine.—*Silver oxide,* Ag_2O, is formed when a salt of silver is precipitated by pure potassium hydrate, which throws it down as a brownish substance that blackens on drying. There is also a black powder, probably another oxide, produced when Ag_2O is digested with ammonia. It is very explosive when dried, a mere touch with a feather effecting its decomposition. It is known as Berthollet's fulminating silver. Its exact composition is doubtful.

Silver chloride, AgCl, occurs native as *horn silver* (cerargyrite). It is produced artificially by the addition of hydrochloric acid or sodium chloride to a soluble salt of silver. It is then thrown down as a dense, white, flocculent precipitate, that changes to a dark violet on exposure to sunlight. This change is due to a partial decomposition. Silver chloride is readily dissolved by sodium hyposulphite.

Silver iodide, AgI, and *silver bromide,* AgBr, together with silver chloride, are extensively employed in photography, owing to the ease with which they are decomposed by the action of light.

The common card photographs, or *silver prints,* as they are technically called, are formed by exposing paper covered with silver chloride to the action of light. The ordinary processes of photography produce on a glass plate a *negative picture,* that is, a picture in which the light portions of the object are black, and the black portions light. This is due to the fact that the light from the light portions renders the sensitive salt of silver on the plate insoluble, and when the picture is *fixed,* that is, when all the unaltered salt is removed by the action of some solvent, such as sodium hyposulphite, the dark parts of the object are transparent on the glass and the light parts are opaque.

When, therefore, the negative is placed over the sheet of paper covered with silver chloride and exposed to the action of the sunlight, it acts, so to speak, as a stencil, allowing the light to pass through the transparent parts and darken the paper, while the dark parts remain unaffected. In this way a *positive* picture is obtained.

In order to prevent the picture from being blackened by the light on the removal of the negative, the unaffected silver chloride is removed from the paper by floating it in a solution of sodium hyposulphite.

The picture is now practically covered with metallic silver. In order to make it less influenced by the air, it is submitted to an operation called *toning*, by which the silver is coated with a purple layer of finely divided metallic gold.

214. Silver Nitrate, $AgNO_3$, or *Lunar Caustic.*—This important salt of silver is obtained by dissolving silver in nitric acid. The solution thus formed deposits, when evaporated, transparent rhombic plates, whose specific gravity is 4.3.

Silver nitrate has a burning, acrid taste, and acts as a violent caustic poison. It is much used in medicine in small doses, but especially for outward applications as a cautery. Common salt, if administered in large doses immediately after silver nitrate has been taken, acts as an antidote to the poison. Silver nitrate is largely employed in photography.

The salts of silver give a black precipitate with hydrogen sulphide, and a white precipitate, which blackens in the light, with sodium chloride or hydrochloric acid. Potassium iodide gives a yellow precipitate of silver iodide.

Experiment 62.—Pour a concentrated solution of silver nitrate into a test-tube, and add a drop of mercury to the solution. In a short time the mercury will be covered with a beautiful deposit of metallic silver (Arbor Dianæ), which presents the appearance of a vegetable growth.

Experiment 63.—Write on a piece of white paper with a solution of silver nitrate. Dry it in a darkened room, and then moisten with a solution of common salt. On exposure to the light, the invisible writing blackens.

Experiment 64.—To a solution of silver nitrate in a test-tube add ammonium hydrate, drop by drop, until the precipitate formed is just dissolved. Now add a small quantity of cream of tartar, dissolved in water, and gently heat the tube. The silver will be deposited over the tube as a bright metallic coating.

* * *

SYLLABUS.

The alkalies are substances that have a caustic taste, turn infusion of blue-cabbage green, and turmeric solution from yellow to brown. Their lower oxides are basic.

The metals of the alkalies are potassium, sodium, lithium, cæsium, and rubidium. These, together with silver, are monad metals.

The metals of the alkalies are soft and readily fusible. At sufficiently high temperatures they volatilize. The compound radical ammonium has properties similar to the metals of the alkalies.

Potassium occurs widely distributed in nature. It is found in the animal, vegetable, and mineral kingdoms.

Metallic potassium is obtained by the action of heat on a mixture of potassium carbonate and charcoal in a closed iron retort. The potassium distils over, and is condensed in a suitably shaped receiver.

Metallic potassium is very soft. It has a bluish-white color, and melts at temperatures considerably below the boiling-point of water. At higher temperatures it boils and emits a green vapor.

Potassium has such an energetic affinity for oxygen that it takes it from water, decomposing it and setting free its hydrogen. It is, therefore, a powerful reducing agent.

The principal oxide of potassium is K_2O, the monoxide. When thrown on water it energetically combines with it, forming potassium hydrate, KOH.

Potassium hydrate is prepared commercially by boiling a solution of potassium carbonate to which milk of lime has been added. The residue left after evaporating the filtered liquid is fused and cast in cylindrical sticks.

Potassium hydrate, or caustic potash, is a hard, white, brittle solid, that deliquesces rapidly on exposure to the air. It is a powerful caustic, and is used in surgery. Potash lye, the name given to the aqueous solution, is largely employed in the manufacture of soap.

Potassium chloride, iodide, bromide, and fluoride all crystallize in cubes. The iodide and bromide are extensively employed in medicine.

Potassium nitrate, or saltpetre, occurs native as an efflorescence on the soils of hot, dry countries. It is also prepared from sodium nitrate.

Potassium nitrate is dimorphous. It possesses a bitter, cooling taste, and is very soluble in hot water. Its principal uses are as a medicine, in the manufacture of gunpowder, and in corning meat.

Gunpowder is an intimate mixture of nitre, charcoal, and sulphur.

There are two potassium sulphates, viz.: the neutral, K_2SO_4, and the acid, $KHSO_4$. The latter is the more soluble.

Potassium chlorate is formed by passing chlorine gas through a concentrated solution of potassium hydrate. It crystallizes in white, rhomboidal tables. It is largely employed in the manufacture of oxygen, and possesses powerful oxidizing properties.

There are two carbonates of potassium, viz.: potassium neutral carbonate, K_2CO_3, and potassium acid carbonate, $KHCO_3$. The latter is less soluble than the former.

Potash imparts a characteristic violet color to flame. It yields no precipitate with hydrogen sulphide or ammonium sulphide; forms a white, gelatinous precipitate with hydrofluosilicic acid, and a yellow precipitate with platinum tetrachloride.

The principal natural sources of sodium are the beds of sodium chloride in the earth, or its solution in ocean water or in the waters of inland lakes and seas. Large deposits of nitrate, carbonate, and sulphate also occur.

Metallic sodium is obtained by strongly heating a mixture of sodium carbonate, charcoal, and a little chalk, in a closed retort connected with a suitably arranged receiver.

Metallic sodium has a silvery-white lustre, and possesses properties similar to those of potassium. It decomposes water, yields a colorless vapor if sufficiently heated, and imparts a deep yellow color to flame.

Sodium hydrate, or caustic soda, may be formed by adding sodium monoxide to water. It is prepared commercially by boiling a solution of sodium carbonate, to which milk of lime has been added. It is powerfully caustic, and is used in the manufacture of soap.

Sodium chloride, or common salt, is the most important compound of sodium. It occurs in vast deposits of rock salt, and in solution in oceanic and continental waters.

The rock salt is either mined directly, or water is introduced into borings made into the beds, and pumped out when thoroughly charged with the salt. It is also prepared by the evaporation of sea-water.

Sodium chloride sometimes crystallizes in curious hopper-shaped collections of cubes. This salt is necessary to the existence of animal life.

Sodium carbonate was formerly obtained from the ashes of sea plants. It is now obtained from common salt by Le Blanc's process.

Le Blanc's soda process consists of three distinct steps, viz.: 1st. The conversion of common salt into sodium sulphate; 2d. The decomposition of the sulphate, by exposing it to an intense heat when mixed with chalk and coal; and 3d. The extraction of the soluble carbonate from the mass so produced.

Sodium carbonate crystallizes in oblique rhombic prisms, that effloresce on exposure to the air. It is largely employed in the manufacture of soap and glass, and is used in calico-printing and in washing.

Sodium bicarbonate is made by passing carbonic acid gas over the carbonate. It is used in medicine, for effervescing drinks, and for baking powders.

There are two sodium sulphates, viz.: the neutral, Na_2SO_4, and the acid, $NaHSO_4$.

Borax, or sodium pyroborate, occurs naturally. It is employed as a flux in the welding of metals, keeping their surfaces bright and clean by dissolving the oxides formed on them.

The sodium salts may be detected by the characteristic bright yellow color they impart to flame.

Soluble glass is a tetrasilicate of soda. It is largely employed in the manufacture of artificial stone.

Lithium is a rare metal that occurs in very small quantities widely distributed in nature. It has a silvery white lustre, and possesses a powerful attraction for oxygen.

Lithium imparts a rich crimson color to flame. Like sodium, it can be readily detected by the use of the spectroscope.

Cæsium and rubidium are extremely rare metals that were discovered by Bunsen and Kirchoff by the aid of the spectroscope. Their salts so closely resemble those of potassium that they cannot readily be distinguished therefrom.

Silver is isomeric with the metals of the alkalies. It forms an alum similar to that of potassium.

The principal ores of silver are the sulphide and chloride. These ores occur both pure and associated with copper, arsenic, and antimony. Silver also occurs pure in nature.

Silver is obtained from its ores in one of three different ways, viz.: 1st. By cupellation; 2d. By amalgamation; 3d. By precipitation from a solution of a soluble silver salt by means of copper.

Metallic silver has a pure white color and a high metallic lustre. It is very malleable and ductile, and is an excellent conductor of heat and electricity. It does not tarnish on exposure to the air, but blackens in the presence of sulphuretted hydrogen.

Alloys of silver may be assayed by the dry assay, that is, by cupellation; or by the wet assay, that is, by precipitating a soluble salt by a standard solution of sodium chloride.

The principal salts of silver are the chloride, the iodide, the bromide, and the nitrate. They are all employed in photography.

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QUESTIONS FOR REVIEW.

Describe some of the characteristics of the metals of the alkalies. In what respects does silver resemble these metals?

Explain the origin of the word alkali. Who discovered the compound nature of the alkalies?

Name some of the sources of potassium. How is metallic potassium prepared? Write the reaction that occurs during its preparation.

What danger attends the preparation of potassium? Describe the properties of potassium.

How is potassium hydrate prepared commercially? Write the reaction that occurs in its preparation. Describe the properties of potassium hydrate. Name some of the principal purposes for which it is used in the arts.

Write the chemical formulæ for the sulphide, chloride, bromide, and iodide of potassium.

For what are the iodide and bromide of potassium employed?

What is the principal source of potassium nitrate? From what is it prepared artificially? Describe its properties.

How is gunpowder manufactured? To what does it owe its explosive character?

Write the chemical formulæ for the two sulphates of potassium.

How is potassium chlorate prepared? Write the reaction that occurs during its manufacture. Describe its properties.

Describe some experiments with potassium chlorate.

What two potassium carbonates exist? How are they obtained? Write the chemical formula for each.

Name some of the tests for salts of potassium.

Name some of the sources of sodium. How is metallic sodium prepared? Describe some of its properties.

How is sodium hydrate prepared commercially? Describe some of its properties.

What are the principal commercial sources of common salt? How is common salt obtained from sea-water? What peculiarity is sometimes observed in its crystals?

Describe the Le Blanc process for the manufacture of sodium carbonate from common salt. Write the reaction that occurs in the furnace.

For what purpose is sodium carbonate employed? Write its chemical formula.

Describe the manner of preparation of sodium bicarbonate. Write its chemical formula.

For what purposes is borax employed? What is its composition?

What is the composition of soluble glass? How is it made? For what is it used?

How may the presence of soda salts be ascertained?

What is the principal natural source of lithium? How is it obtained in the metallic state? What are its properties? What are some of the characteristics of the salts of lithium? How may the presence of lithia be detected?

Describe the principles on which spectroscopic analysis is based.

How were cæsium and rubidium discovered? Which of the metals of the alkalies do their salts closely resemble?

Name some of the principal natural sources of silver. In what three ways may its ores be reduced? Describe all of these methods.

Describe some of the properties of metallic silver. For what is it employed? What curious property is possessed by melted silver when exposed to the air?

By what two methods may silver alloys be assayed? Describe each of these methods.

How is silver oxide prepared? How is Berthollet's fulminating silver prepared?

What are some of the properties of silver chloride? How is this salt used in photography?

How is silver nitrate, or lunar caustic, prepared?

SECTION III.

THE TRIAD AND THE PENTAD METALS.

Triads.	Pentads.
1. Gold.	1. Vanadium.
2. Thallium.	2. Columbium.
	3. Tantalum.

CHAPTER X.

GOLD AND THALLIUM.—VANADIUM, COLUMBIUM, AND TANTALUM.

GOLD.

Au = 197. Sp. Gr. = 19.34. Quantivalence = I., III. Molecular weight = 394. Free molecule, Au ≡ Au?

215. Occurrence and Extraction.—Gold occurs in nature mainly in the metallic state, crystallized either in cubes or octahedra, as in Fig. 113, or in tetrahedra, but it more frequently occurs in thin plates, or in nodules or nuggets. These latter are in rare instances several pounds in weight. Gold is found in the sands of rivers, or in quartz rock and granite, in many parts of the world. It sometimes occurs combined with other metals, such as silver, copper, and tellurium, or associated with iron pyrites.

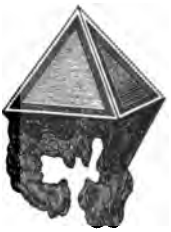

Fig. 113.
Crystal of Gold.

The high specific gravity of gold renders its extraction comparatively easy. The auriferous sand is washed in wooden troughs called cradles, when the metallic gold sinks to the bottom, and the mud, sand, and other impurities are poured off with the water. If the gold occurs in thin plates, in quartz, or other rock, the latter is first crushed to a powder in the stamping-mill, and then washed. If, as is often the case, the gold occurs in very fine powder, it is separated by amalgamation; the ground ore being agitated with mercury, by which the gold is dissolved. The gold is then extracted from the mercury by distillation.

Native gold is seldom pure, but is alloyed with other metals, especially with silver. These metals may be separated from the gold by dissolving the mass in strong nitric acid, when the pure gold is left in a finely divided state.

216. Properties of Gold.—Pure gold has a rich yellow color, and a beautiful metallic lustre. Though opaque in the mass, it is transparent in thin leaves, transmitting a greenish light. It is more ductile and malleable than any other metal, and is nearly the best conductor of heat and electricity. It may be beaten into leaves so thin that about 300,000 would be required to be piled one on another to equal an inch in thickness. At temperatures above its point of fusion, it emits a greenish vapor. On cooling, melted gold shrinks, so that it cannot readily be cast into any desired shape.

Gold is not affected by exposure to air or moisture. It is not dissolved by ordinary acids, but is readily attacked by chlorine. The solvent for gold is aqua regia.

Experiment 65.—Fasten a thin sheet of pure gold leaf to a clean plate of glass, by slightly moistening the glass by the breath. When quite dry, protect it by a thin layer of transparent varnish. The gold leaf will now appear yellowish red by reflected light, but green by transmitted light.

Experiment 66.—Drop a small piece of pure gold leaf in a test-tube containing a little pure nitric acid, and another piece in a test-tube containing pure hydrochloric acid. Boil each of these and observe that the gold is not dissolved. Now pour the two together and heat, and in a short time the gold will be dissolved and will color the liquid yellow.

217. Auric Chloride, or Trichloride of Gold, $AuCl_3$, is produced when gold is dissolved in aqua regia. On evaporating the solution at a low temperature, a red deliquescent mass of crystals remains, which is the trichloride. It is readily soluble in water, with which it forms an orange-colored solution when strong, and yellow when dilute. It stains the skin violet.

Auric chloride is readily decomposed. Its decomposition is effected by light and heat; by phosphorus; by phosphorous, hypophosphorous, and sulphurous acids; and by heated carbon.

Experiment 67.—Dip the outside of a clean test-tube in a solution of auric chloride, and then heat it. The metallic gold will be deposited on the outside of the glass in the form of a fine gold plating.

Auric chloride yields a brown precipitate of pure metallic gold by the addition of a solution of ferrous sulphate. The following reaction occurs, viz.:

$$\underset{\text{Ferrous Sulphate}}{6SO_4Fe} + \underset{\text{Auric Chloride}}{2AuCl_3} = \underset{\text{Ferric Sulphate}}{2(SO_4)_3Fe_2} + \underset{\text{Ferric Chloride}}{Fe_2Cl_6} + \underset{\text{Gold}}{Au_2}$$

By adding, drop by drop, a mixture of stannous and stannic chlorides to neutral auric chloride, a flocculent purple precipitate, called the Purple of Cassius, is obtained, which is employed for painting on glass.

The *protochloride of gold*, AuCl, is formed when the trichloride is gently heated.

There are two oxides of gold, viz., *gold monoxide*, Au_2O, which, digested with ammonia, forms *fulminating gold;* and *gold trioxide*, Au_2O_3, or auric acid, which forms compounds with bases.

218. Alloys of Gold—Assaying—Characteristics of the Salts of Gold.—Like silver, gold is too soft a metal to be used in a pure state for coin, jewelry, or gold plate. In order to increase its hardness it is generally alloyed with copper and silver. When used for coin, gold is alloyed with copper. The standard gold coin of the United States contains ten per cent. of copper. Jewelry is an alloy of gold, silver, and copper.

The fineness of the alloy is sometimes expressed by the word *carat*, 24 carat being pure gold. Five different carats exist, viz., 22, the standard for gold ware, 18, 15, 12, and 9 carat gold, these numbers indicating that 24 parts by weight of 22 carat gold contains 22 parts of pure gold; 24 parts by weight of 12 carat gold contains 12 parts by weight of pure gold, etc.

The percentage of gold present in an alloy is determined by assaying the alloy.

The method adopted for this purpose is *cupellation*. A carefully weighed specimen of the alloy is melted with sufficient silver to equal at least three times that of the gold, and all the metals but the gold and silver are removed by cupellation. The button remaining in the cupel on the completion of the process is hammered into a thin sheet and treated with hot nitric acid, which dissolves out all the silver, and leaves the gold in a slightly coherent mass, which, when washed, heated, and finally weighed, gives the quantity present in the alloy.

The salts of gold give a characteristic brown precipitate on the addition of ferrous sulphate. They are reduced to a metallic state by boiling with a soluble sulphite. They yield the purple of Cassius by the addition of dilute stannous and stannic chlorides.

THALLIUM.

Tl = 204. Sp. Gr. = 11.9. Fusing point = 561° F. Discovered by Crookes in 1861.

219. Preparation and Properties.—The metal thallium is another element that was discovered by the aid of the spectroscope. By examining spectroscopically a specimen of a seleniferous deposit in the lead chamber of a sulphuric acid manufactory, Crookes discovered the existence of the new element by its characteristic spectrum, which consists of a single bright green line. He named it thallium, from *θάλλος*, a green twig.

Metallic thallium is obtained from the seleniferous deposit above mentioned by repeated boiling with very dilute sulphuric acid and then precipitating the thallium by zinc, on which it is deposited as glittering needles or plates. It is a bluish-white metal, resembling lead in its metallic lustre. It is very soft and streaks paper like graphite. It volatilizes at a high temperature, emitting a pale red vapor, that possesses a peculiar smell. It dissolves readily in dilute acids.

Thallium forms two oxides, viz., *thallium monoxide,* Tl_2O, and *thallium trioxide,* Tl_2O_3. From these an extensive series of salts, the thallious and the thallic salts are formed. All these salts are poisonous and possess a disagreeable metallic taste. They are easily detected by the beautiful green color they give to an otherwise non-luminous flame.

The exact chemical place of thallium among the elements is as yet uncertain. In some respects it resembles the alkaline metals, forming a decidedly alkaline hydroxide, TlOH, and forming a thallium alum by replacing the alkaline metals in alum. But then, on the other hand, it resembles lead in its haloid salts, and in its black sulphide.

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220. The Pentad Metals.—The three pentad metals, vandium, niobium (or columbium), and tantalum are all exceedingly rare.

VANADIUM.

V = 51.37. Sp. Gr. = 5.5. Discovered by Sefström in 1830.

221. Preparation and Properties.—Vanadium occurs in only a few rare minerals, though traces are found moderately well distributed.

Metallic vanadium, prepared by reducing the dichloride in hydrogen, occurs as a whitish-gray powder, which under the microscope shows a crystalline structure and a silver-white lustre. It oxidizes but slowly in the air. Nitric acid oxidizes the metal violently, and forms a blue solution. It is not attacked by either cold or hot hydrochloric acid, nor by dilute cold sulphuric acid; but the latter acid when hot dissolves it, and forms a greenish-yellow solution.

Vanadium forms numerous salts. With oxygen it forms compounds analogous to the oxides of nitrogen. Its compounds are comparatively unimportant.

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NIOBIUM (OR COLUMBIUM).

Nb = 94. Sp.Gr. = 4.06. Discovered by Hatchett in 1801.

222. Occurrence and Properties.—This very rare metal was discovered by Hatchett in a mineral called columbite, and was named by him Columbium. It was afterwards believed, by Wollaston, to be identical with the rare metal tantalum. This opinion prevailed until 1846, when it was shown that tantalum and columbium were distinct elements. The metal Columbium was then called Niobium, a name by which it is now generally known.

Metallic niobium is obtained as a steel-gray crust, that, when heated in air, oxidizes so rapidly as to become incandescent. Hydrochloric and nitric acids do not affect it, but it readily dissolves in concentrated sulphuric acid and produces a colorless liquid.

Niobium produces a variety of salts, none of which are of much practical importance.

TANTALUM.

Ta = 182. Discovered by Ekeberg in 1803.

223. Occurrence and Properties.—This rare metal was discovered by Ekeberg while he was investigating the yttrium minerals. The name tantalum was given because, like Tantalus, the metal is unable, though surrounded by different acids (nitric, sulphuric, hydrochloric, or even aqua regia), of saturating itself with them. It is probable, however, that the metal has not yet been obtained pure. It forms a number of comparatively unimportant salts.

SYLLABUS.

The triad metals are gold and thallium. The pentad metals are vanadium, niobium or columbium, and tantalum.

Gold occurs naturally almost entirely in the native or pure state in the sands of rivers, or in quartz or granite. It is extracted from sands and mud by washing in cradles; from quartz and other hard rocks by reducing them to a powder, and removing the gold by mercury.

Native gold is seldom pure. It is generally alloyed with silver or other metals.

Gold has a rich yellow color, and a beautiful metallic lustre. In thin films it transmits a greenish light. It is the most malleable and ductile of all the metals, and nearly the best conductor of heat and electricity.

At high temperatures gold volatilizes and emits a greenish vapor. Gold is not dissolved in any acid except aqua regia.

Auric chloride, $AuCl_3$, is produced by dissolving gold in aqua regia. It crystallizes in red, deliquescent crystals, that, when gently heated, yield the protochloride $AuCl$.

Auric chloride is readily decomposed by heat. If a test-tube be dipped in a solution of this salt and gently heated, it will be gilded by a film of metallic gold.

If a solution of ferrous sulphate be added to a solution of auric chloride, a brown precipitate of metallic gold is obtained.

The purple of Cassius is obtained by gradually adding a mixture of stannous and stannic chlorides to a solution of auric chloride.

Pure gold is too soft to be used directly for jewelry, coin, or plate, and therefore is generally alloyed with copper or silver.

Gold coin is generally alloyed with copper. Gold jewelry is alloyed with copper and silver.

The percentage of gold present in any alloy is determined by assaying the alloy by cupellation.

The salts of gold are recognized by giving with ferrous sulphate a brown precipitate of metallic gold; by yielding the purple of Cassius on the addition of stannous and stannic chlorides, and by being reduced to metallic gold by boiling with a soluble sulphite.

Thallium was discovered by Crookes in 1861, by the use of the spectroscope. It gives a bright green light. Its name is derived from θάλλος, a green twig.

Metallic thallium is obtained by the precipitating action of zinc on a liquid obtained by repeatedly boiling the seleniferous deposits of certain sulphuric acid chambers in dilute sulphuric acid.

Metallic thallium is a bluish-white metal, somewhat resembling lead, which volatilizes at a high temperature, emitting a pale-red vapor.

All the salts of thallium are poisonous, and possess a disagreeable metallic taste. They impart a characteristic green color to flame.

Vanadium is a rare metal, discovered by Sefström in 1830. Metallic vanadium has a silver-white lustre. It dissolves violently in nitric acid, producing a blue liquid. Its oxides correspond in composition to the oxides of nitrogen.

Niobium was formerly called Columbium. It was discovered by Hatchett in 1801.

Tantalum was discovered in the yttria minerals by Ekeberg in 1803. It has probably not yet been obtained in a pure state.

QUESTIONS FOR REVIEW.

Name the triad metals. Name the pentad metals.

In what form does gold usually occur in nature? By what two processes is it extracted from its deposits? In what system does it crystallize?

Describe the process of cradling. Describe the process of amalgamation. Under what circumstances is the latter process employed?

With what metal is native gold generally alloyed?

Describe the properties of pure gold.

How may the transparency of pure gold be shown? What acid is employed to dissolve gold?

How is auric chloride prepared? Describe some of its properties. How is the protochloride of gold obtained?

Write the reaction that occurs when auric chloride is mixed with ferrous sulphate.

How is the purple of Cassius obtained?

Why is not pure gold used for coin or jewelry? With what metals is gold usually alloyed for these uses?

Explain what is meant by an 18-carat gold. By a 12-carat gold.

Describe in full the method employed for assaying gold.

Name some of the characteristic tests for the salts of gold.

When and by whom was thallium discovered? How was the discovery made? Describe some of the properties of metallic thallium.

Name some of the characteristics of the salts of thallium.

In what respects is the exact position of thallium among the chemical elements uncertain?

When and by whom was vanadium discovered?

Describe some of the properties of metallic vanadium.

Who discovered niobium? What name was originally applied to this element? Describe some of the properties of metallic niobium.

When and by whom was tantalum discovered? What is the origin of its name?

THE ARTIAD METALS.

SECTION IV.

THE DYAD METALS.

Group I.

Metals of the Alkaline Earths.

1. Barium.
2. Strontium.
3. Calcium.
4. Lead.

Group II.

Metals of the Earths.

1. Aluminium.
2. Glucinum or Beryllium.
3. Thorium.
4. Yttrium.
5. Erbium.
6. Terbium.
7. Cerium.
8. Lanthanum.
9. Didymium.
10. Zirconium.

Group III.

Metals of the Magnesium Group.

1. Magnesium.
2. Zinc.
3. Cadmium.

Group IV.

Metals of the Mercury Group.

1. Mercury.
2. Copper.

CHAPTER XI.

Barium, Strontium, Calcium, and Lead.

224. The Metals of the Alkaline Earths.—Barium, strontium, and calcium are called the metals of the alkaline earths. The alchemists applied the term "earth" to those non-metallic substances that are insoluble in water and unalterable in air, even when exposed to a high temperature. Since some of these earths were found to possess alkaline properties, the name was still retained after the earths were shown by Davy not to be elements, but combinations of metallic substances with oxygen. The metals of the alkaline earths are dyads, that is, are capable of replacing two atoms of hydrogen from its compounds. They readily decompose water at all temperatures, and form oxides, the lowest of which is readily hydrated. These metals form powerful bases; their oxides form bleaching powders with chlorine; their carbonates are insoluble in pure water, but soluble in water containing carbonic acid.

* * *

BARIUM.

Ba = 137. Recognized as an element by Davy in 1808.

225. Occurrence and Properties.—Barium occurs naturally in large quantities as *heavy spar*, or barium sulphate, and *witherite*, or barium carbonate.

Metallic barium may be obtained by the decomposition of fused barium chloride by means of electricity. It possesses a silver-white lustre, and has a very strong affinity for oxygen, tarnishing rapidly in the air and readily decomposing cold water. Heated in the air, it burns with great brilliancy.

226. Oxides of Barium.—There are two oxides, viz., barium monoxide, BaO, or baryta, and barium dioxide, BaO_2.

Barium monoxide, BaO, is obtained by decomposing barium nitrate by a red heat. It is a porous, whitish-gray mass, that slakes violently when moistened with water, evolving considerable heat and forming barium hydrate, $Ba(OH)_2$. The valuable reagent, *baryta-water*, is an aqueous solution of this hydrate.

Barium dioxide, BaO_2, is obtained as a porous, grayish mass by heating pure baryta to redness in a current of dry oxygen.

227. Barium Monosulphide, BaS, is produced by roasting heavy spar with coal and a little starch; thus:

$$BaSO_4 + C_4 = BaS + 4CO$$

Barium Sulphate + Carbon = Barium Monosulphide + Carbon Monoxide.

Barium monosulphide is important as forming a ready means for forming the salts of barium from the insoluble sulphate; for, when barium sulphide is treated with any acid, it is readily decomposed, the corresponding barium salt is formed and hydrogen sulphide liberated; thus:

$$\underset{\text{Barium Monosulphide}}{BaS} + \underset{\text{Hydrochloric Acid}}{2HCl} = \underset{\text{Barium Chloride}}{BaCl_2} + \underset{\text{Hydrogen Sulphide.}}{H_2S}$$

Experiment 68.—In order to produce a variety of *luminous paint*, heat five parts of precipitated barium sulphate with one part of powdered charcoal for half an hour over an ordinary gas-flame, and then heat more intensely for ten minutes in a furnace or by a blow-pipe flame. Seal the mass while hot in glass tubes. These tubes now possess the power of phosphorescing; that is, when exposed to sunlight, they will continue to shine with a bright orange light for some time after removal to a dark room.

228. Barium Chloride, $BaCl_2+2H_2O$, is obtained by the action of hydrochloric acid on barium monosulphide. The chloride thus formed yields colorless rhombic crystals, Fig. 114, that contain two molecules of water. A solution of barium chloride is extensively employed in the laboratory as a test for sulphuric acid. The salt has an unpleasant taste and is quite poisonous.

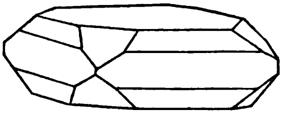

Fig. 114.—Barium Chloride.

229. Barium Sulphate, $BaSO_4$, occurs native in the mineral heavy spar, in veins usually accompanying ores of lead or of some other metal. This is a very heavy mineral; its specific gravity is 4.48, and has served to give the name to barium, which is derived from the word βαρὺς, heavy. It may be prepared artificially by precipitating any soluble salt of barium by sulphuric acid. It is a white substance. Large quantities are prepared in this manner from the chloride, for the adulteration of white lead, or as a permanent white for water-color painting. Barium sulphate is insoluble in water and in all acids except boiling concentrated sulphuric. It is used as an adulterant for white paint.

230. Barium Nitrate, $Ba(NO_3)_2$, may be obtained by the action of nitric acid on barium monosulphide. The filtered solution so produced yields, on evaporation, transparent octahedral crystals, or modified octahedra. When heated, barium nitrate gives off most of its oxygen. It is largely used in the manufacture of the green fires of the pyrotechnist.

Experiment 69.—To make green fire, intimately mix 450 parts by weight of dry barium nitrate, 150 parts of sulphur, and 25 parts of lampblack. Then, *in a separate mortar*, coarsely powder 100 parts of potassium chlorate, and using the fingers only, *carefully* mix with the other ingredients. This powder will burn with a bright green light.

231. Barium Carbonate, $BaCO_3$, occurs naturally as *witherite.* It may be prepared artificially by the action of an excess of barium chloride on a hot solution of ammonium carbonate, when it is precipitated as a dense white powder. It is sometimes used as a rat poison; it is also employed as a substitute for part of the potash and lead in the manufacture of plate and flint glass.

232. Characteristics of the Salts of Barium.—The presence of any soluble barium salt may be readily detected by the dense white precipitate (insoluble in acid) formed by the addition of sulphuric acid.

Most of the salts of barium are colorless; all the soluble salts are poisonous. The best antidote for barium poisoning is sodium or magnesium sulphate.

Barium salts impart a yellowish-green color to an alcohol flame.

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STRONTIUM.

Sr = 87.5. Sp. Gr. = 2.58. Quantivalence = II., IV. Discovered by Davy in 1808.

233. Occurrence and Properties.—Strontium does not occur so abundantly in nature as barium. Its principal mineral sources are *celestine,* or strontium sulphate, and *strontianite,* or strontium carbonate. Strontium closely resembles barium in its properties.

Metallic strontium may be obtained by decomposing the fused chloride by electricity. It is of a pale yellow color, and burns, when heated in air, with a crimson flame. It oxidizes quickly in the air, and decomposes water vigorously.

234. Oxides of Strontium.—There are two oxides of strontium, viz., the monoxide and the dioxide.

Strontium monoxide, SrO, is obtained by decomposing the nitrate by heat; it is of a grayish-white color, and is infusible. It unites with water to form a crystalline hydrate, $Sr(OH)_2+8H_2O$, a solution of which forms the reagent known as strontia water. This substance possesses caustic properties, and is strongly alkaline.

Strontium dioxide, SrO_2, forms with water a crystalline hydrate, SrO_2+8H_2O.

235. Strontium Nitrate, $Sr(NO_3)_2$, is prepared by decomposing strontium sulphide in nitric acid. It is an anhydrous salt that crystallizes in transparent octahedra. Like potassium nitrate, it possesses a cooling taste. It is largely employed in fireworks in the manufacture of red fire.

Experiment 70.—To make a red fire, intimately mix in a mortar 800 parts by weight of dry strontium nitrate, 225 parts of sulphur, and 50 parts of lamp-black. Coarsely granulate, *in a separate mortar*, 200 parts of potassium chlorate, and using the fingers only, *carefully* mix with the other ingredients. The powder so prepared burns freely with a beautiful crimson flame. It is preferably used shortly after making, as it has been known to ignite spontaneously.

236. Other Compounds of Strontium.—*Strontium carbonate*, $SrCO_3$, may be obtained artificially by precipitating any soluble strontium salt by a soluble carbonate. So formed, it occurs as a heavy, white, impalpable powder.

Strontium sulphate, $SrSO_4$, may be obtained artificially by precipitating a strontium salt by a soluble sulphate.

Strontium chloride, $SrCl_2$, is obtained by dissolving the native carbonate in hydrochloric acid. The concentrated solution deposits, while still hot, elongated hexagonal crystals, having the composition $SrCl_2+6H_2O$, which have a sharp, bitter taste, and effloresce on exposure to the air. This salt is slightly soluble in alcohol, to the flame of which it imparts a reddish color.

237. Characteristics of the Strontium Salts.—The salts of strontium may be detected by the magnificent crimson color they impart to flame. Though to the eye this color resembles that produced by lithium, yet in the spectroscope it is quite different.

All the strontium salts are colorless. They are not poisonous, but have a disagreeable, bitter taste.

CALCIUM.

Ca = 40. Sp. Gr. = 1.57. Quantivalence = II. and IV.

238. Occurrence, Preparation, and Properties.—Calcium is one of the most abundant of the chemical elements, and is very extensively diffused in nature. Its principal natural source is *limestone*, or calcium carbonate, which occurs in immense deposits, whole mountain ranges being formed almost entirely of this mineral associated with magnesium. It also occurs in large quantities in other minerals.

Metallic calcium may be obtained by the electrical decomposition of the fused chloride. It is a yellow metal with a silvery-golden lustre, harder than lead, and can be readily hammered into thin sheets. It is but slowly oxidized in dry air, but combines rapidly with oxygen in the presence of moisture, decomposing water when thrown in it, and forming calcium hydrate. When heated to redness in air, it burns with a brilliant yellowish-white light.

Metallic calcium combines with mercury, forming an amalgam. When heated, metallic calcium combines directly with the vapors of sulphur, iodine, and bromine, and with chlorine gas, with the evolution of luminous heat.

239. Calcium Oxide, and Calcium Hydrate.—*Calcium oxide*, CaO, is obtained by calcining any of the varieties of limestone. This process is conducted in the well-known limekilns. The burning requires about forty-eight hours, when the kiln is allowed to cool, and the limestone is found to be converted into a white caustic powder, known as *quicklime.*

Calcium oxide is an exceedingly *refractory* substance, that is, it cannot readily be melted by the most intense heat. Its use in the calcium light has already been mentioned.

Calcium hydrate, $Ca(OH)_2$, is formed when water is thrown on quicklime. The water is absorbed, and the lime swells, splits into pieces, and finally becomes changed into a white powder, commonly known as slaked lime.

Nearly all fertile soils contain lime, and many have their fertility increased by the addition of this substance, which promotes the decay of vegetable matter, and liberates the potash of the soil from its insoluble silicate.

Considerable heat is evolved during the slaking of lime, and fires have been caused in this manner.

When quicklime is exposed to the air it gradually absorbs carbonic acid and moisture, and becomes converted into a fine white powder, consisting of the carbonate and the hydrate. It is then said to be *air-slaked.*

Calcium hydrate is soluble in about seven hundred parts of cold water, the solution forming *lime water.* It is less soluble in hot water, which is a marked exception to nearly all other soluble substances.

Experiment 71.—Prepare some lime water by adding freshly-slaked lime to cold water, allowing it to stand in a corked bottle for several days, and occasionally shaking it. Pour some of the clear liquid in a clean test-tube and heat it over a Bunsen burner or a spirit flame, and the liquid will become white from the deposition of part of the lime the hot water is unable to dissolve.

Milk of lime is calcium hydrate mixed in less water than can dissolve it.

240. Mortars and Cements.—Ordinary mortar consists of quicklime made into a stiff paste with water. To prevent shrinkage and to increase the coherence of the mass, it is mixed with from three to four parts of sharp sand. This mortar hardens on exposure to the air, both from the absorption of carbonic acid gas on the surface, and also, it would appear, from the change of each grain of sand on its surface into a hydrated calcium silicate. Mortar continues to harden for many years after it has set.

The quality of mortar depends on the purity of the lime. *Rich* or *fat limes* contain the least impurities, and swell considerably in slaking. *Poor limes* contain magnesia, silica, or alumina, and do not swell on slaking with water. The pure limes form ordinary mortar; when finely divided silica or clay is present in about from ten to thirty per cent., the lime, mixed with sand, forms a *hydraulic mortar*, which possesses the property of hardening under water, and is, therefore, suitable for the masonry of the foundations of bridges, piers, etc.

Cement is a valuable form of lime that, when mixed into a paste with water, possesses the valuable property of rapidly setting or hardening. It is obtained from limestone containing clay, or may be produced by mixing lime and clay and rèburning them.

241. Calcium Chloride, $CaCl_2$, may be obtained by the action of hydrochloric acid on marble or chalk. When all evolution of gas has ceased, the liquid is concentrated by evaporation, and deposits six-sided prismatic crystals, whose composition is $CaCl_2+6H_2O$. They are very deliquescent, and dissolve so rapidly in water as to produce a considerable reduction of temperature. Mixed with powdered ice or snow they form an excellent freezing mixture, lowering the temperature to —47° F. Exposed to a prolonged and moderately intense heat they lose their water and enter into fusion, forming the *fused calcium chloride*, so much employed in the drying of gases. In this form it has an exceedingly powerful attraction for water.

242. Compounds of Calcium with Sulphur and Fluorine.—*Calcium proto-sulphide*, CaS, may be prepared from the sulphate by heating it when mixed with charcoal. When freshly made it possesses the power of phosphorescing on exposure to the light.

Experiment 72.—Another variety of luminous paint may be prepared as follows, viz.: Calcine some oyster-shells in an open fire for half an hour; select the whitest portions and mix them with one-third their weight of flowers of sulphur; pack them in a crucible with a luted cover, and heat strongly for about an hour; when cold, the crucible is broken, and the contents are placed in sealed glass tubes or well-stoppered bottles. They will continue to shine in the dark for a long time after exposure to bright sunlight.

Calcium fluoride, CaF, occurs naturally as fluor-spar, the chief source of the element fluorine. It crystallizes in cubic forms, and occurs of various colors—blue, green, and white. It exists in the bones and teeth of animals.

Many specimens of fluor-spar possess the curious property of emitting a pale-green or violet phosphorescent light when gently heated in the dark.

243. Calcium Carbonate, $CaCO_3$, and its Varieties.—Calcium carbonate occurs in nature in a variety of forms, viz., as limestone, marble, chalk, calc-spar, arragonite. The last two varieties, calcspar and arragonite, are good instances of *dimorphism*, the former crystallizing in hexagonal forms, and the latter in rhombic prisms. Crystals of calcspar are shown in Fig. 115.

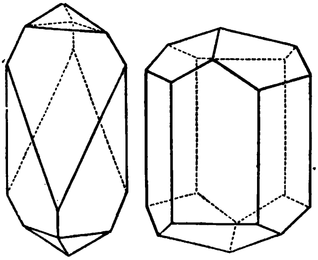


Fig. 115.—Calcspar.

Calcium carbonate is but sparingly soluble in pure water, but is readily soluble in water containing carbonic acid. Some springs contain in their waters a large quantity of lime, which, on reaching the surface, they deposit in masses of limestone called travertine.

Water containing lime in solution is called *hard water*, and will not yield a lather with soap until all the lime present has combined with the soap and formed an insoluble compound. *Soft water* is water free from lime.

Steam-boilers, after being used for periods of time dependent on the character of the water employed, become coated on the inside with a hard deposit, consisting, generally, of carbonate of lime. This deposit is due to the fact that, since only the water is evaporated, all the mineral matters previously held in solution must remain in the boiler.

244. Calcium Sulphate, $CaSO_4$, occurs in nature in two forms—as *anhydrite*, or the anhydrous sulphate, and as *gypsum*, or the hydrated sulphate; the name *selenite* is sometimes given to the regularly-crystallized variety of gypsum.

Gypsum, $CaSO_4 + 2H_2O$, is employed in large quantities for the preparation of plaster, which is obtained by heating the gypsum in closed vessels, by which means its water of crystallization is expelled. The calcined mass, reduced to a fine powder, forms *Plaster of Paris;* and when mixed with water soon solidifies and again forms the same hydrate. It is much employed for the production of moulds, for casts, and for the cornices of ceilings.

Experiment 73.—Half fill a glass beaker with a saturated solution of calcium chloride, diluted with one-half its bulk of water. Then, at arm's length, add, all at once, an equal bulk of dilute sulphuric acid, and gently agitate. The beaker is now filled with calcium sulphate, which soon sets, permitting the vessel to be inverted without its contents running out.

245. Chlorinated Lime, or Bleaching Powder, is obtained by passing chlorine gas over well-slaked lime. It is prepared in large quantities at the alkali works, in order to utilize the evolved hydrochloric acid. It was formerly believed to be a mixture of the chloride and the hypochlorite, thus: $CaCl_2 + Ca(ClO)_2$; but this has been shown to be incorrect.

Chlorinated lime is a powerful bleaching agent, and is employed in large quantities for the bleaching of cotton, and paper pulp.

246. Other Salts of Calcium. Characteristics of Lime Salts.—A number of calcium phosphates exist, and may be obtained by precipitation from calcium chloride by the addition of the corresponding sodium phosphates. Bones consist mainly of a tri-calcium phosphate. Some of the calcium phosphates are extensively employed as fertilizers.

Calcium nitrate, $Ca(NO_3)_2+4H_2O$, may be obtained by adding nitric acid to the carbonate. It crystallizes in oblique rhombic prisms, that are soluble and deliquescent.

The salts of calcium are colorless, and yield no precipitate with hydrogen sulphide, ammonium sulphide, or with soluble calcium sulphate. They yield a white precipitate with oxalic acid, and impart a greenish-yellow tint to flame.

◆

LEAD.

$Pb = 207$. Sp. Gr. $= 11.3$. Quantivalence = II., IV.

247. Occurrence and Metallurgy.—Although various ores of lead occur, yet nearly all the lead of commerce is obtained from the sulphide, or *galena,* a mineral which occurs in immense deposits in various parts of the world.

The process by means of which lead is generally obtained from galena is as follows, viz.: the crushed ore is introduced into a reverberatory furnace, built as shown in Fig. 116.

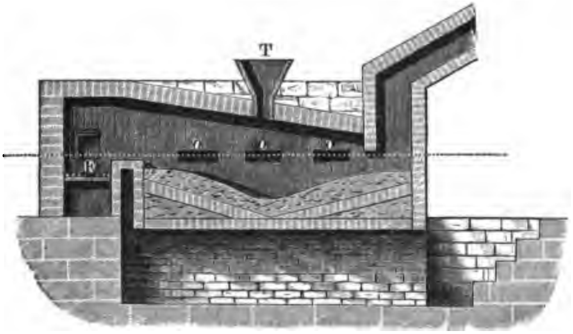


Fig. 116.—Reduction of Galena.

This furnace is furnished with apertures, *o, o, o,* which may be opened or closed at pleasure. A hopper at T is provided for the introduction of the ore. The hollowed form given to the hearth permits the molten metal to be run out through an opening at the lowest point. The flame from the fire at F plays over the surface of the ore.

At first the ore is roasted, that is, it is heated and stirred while the openings admit the outer air. By this process the sulphide is partially converted into oxide and sulphate. When this is effected the openings are closed and the heat increased. The unoxidized sulphide now reacts with the oxide and sulphate, liberating the lead and forming sulphurous oxide; thus:

$$\underset{\text{Lead Sulphide}}{PbS} + \underset{\text{Lead Monoxide}}{2PbO} = \underset{\text{Lead}}{3Pb} + \underset{\text{Sulphurous Oxide.}}{SO_2}$$

$$\underset{\text{Lead Sulphide}}{PbS} + \underset{\text{Lead Sulphate}}{PbSO_4} = \underset{\text{Lead}}{2Pb} + \underset{\text{Sulphurous Oxide.}}{2SO_2}$$

Generally several successive oxidations and reductions are requisite in order to remove all the lead from the charge.

The lead so obtained nearly always contains silver, which is separated from it by the cupellation process already described.

248. Properties and Uses of Lead.—Lead is a soft, bluish-white metal, possessing moderate ductility and malleability. It fuses at 620° F. and volatilizes at a white heat. A freshly-cut surface of lead presents a bright metallic lustre, which soon tarnishes on exposure to the air by the formation of lead oxide. On exposure to air and moisture, lead becomes covered with a layer of carbonate. Metallic lead is rapidly dissolved by nitric acid, and by boiling concentrated hydrochloric and sulphuric acids.

Lead is employed in immense quantities in the manufacture of shot, bullets, lead-pipe, and sheet-lead; for lining tanks, sulphuric acid chambers, roofs, etc.; for the production of various alloys, and in the manufacture of paints.

249. The Oxides of Lead.—Lead combines with oxygen to form a number of oxides.

Lead monoxide, PbO, *litharge*, or *massicot*, is produced in large quantities by passing a current of air over the molten metal. A scaly crystalline mass, of a reddish color, called *litharge,* is produced. If the temperature be too low to fuse the oxide it occurs as an amorphous yellow powder called *massicot.* Lead oxide melts at a red heat, and is readily reduced by charcoal, hydrogen, or carbon monoxide.

Litharge is used in the arts for the manufacture of flint glass; as a glaze for earthenware, and for imparting to linseed oil its drying properties. It is used in the preparation of common adhesive plaster, and of various paints.

Minium, or *red lead,* Pb_3O_4, is produced by heating finely-divided massicot to a temperature below its point of fusion. The heating is conducted in reverberatory furnaces, and is continued for about twenty-four hours, the mass being frequently stirred, and carefully kept at the proper temperature. A crystalline, granular, scarlet powder is thus obtained, which is the red lead of commerce. It is largely used as a paint, and in the manufacture of flint glass. It is also used for coloring sealing-wax. Mixed with oxide of tin it forms a glaze for common earthenware. When mixed with white lead and made into a paste with oil, it forms an excellent cement for the joints of gas- and steam-pipes.

Earthenware glazed with lead should be carefully avoided for culinary purposes, since vinegar or other acids often dissolve sufficient lead from the glaze to poison the food.

250. The Chloride and the Iodide of Lead.—*Lead chloride,* $PbCl_2$, is readily prepared by the action of hydrochloric acid on lead oxide. When dissolved in boiling water, and mixed with lime-water, a snow-white precipitate of *oxychloride,* $Pb(OH)Cl$, is formed, which is largely employed as a paint. Another oxychloride, known as Turner's yellow, much esteemed as a paint, also exists. Lead chloride is almost insoluble in cold water.

Lead iodide, PbI_2, is a beautiful yellow pigment produced by precipitating lead acetate by potassium iodide. It is insoluble in cold water.

251. The Nitrate, the Sulphate, and the Chromate of Lead. —*Lead nitrate*, $Pb(NO_3)_2$, may be prepared by dissolving litharge in hot, dilute nitric acid. It crystallizes in milk-white octahedra. It is largely used in calico-printing, in dyeing, and in the manufacture of chrome-yellow.

Lead sulphate, $PbSO_4$, occurs naturally in the mineral *anglesite*, in transparent rhombic crystals. It is readily obtained artificially as a heavy white powder by precipitating any soluble lead salt by a sulphate, or by dilute sulphuric acid.

Lead chromate, $PbCrO_4$, forms the beautiful pigment known as *chrome-yellow*. It is prepared by precipitating a dilute solution of lead acetate by anhydrous potassium chromate. By boiling chrome-yellow with lime a beautiful scarlet pigment is obtained, which is a basic chromate.

252. Lead Carbonate, $PbCO_3$, or *white lead*, occurs crystallized in nature as the mineral *cerusite*, or may be prepared artificially as an amorphous white powder, largely employed for a white paint. There are several methods employed for its manufacture, the oldest, called the Dutch process, being the most esteemed, as giving a paint possessing the greatest body, *i. e.*, covering properties. A sheet of lead, rolled in a loose spiral, as shown in section at C, Fig. 117, is placed inside a glazed earthenware pot, P, provided with a projection, *d*, on which the lead is supported, and below which a quantity of vinegar, *v*, is placed. The pots are then covered with sheets of lead, D, and placed in rows, in a large chamber, on a bed of rotting manure or old tan, and covered with a board. Manure is spread on this board, and on it is placed another row of pots, similarly charged with lead and vinegar, which are again covered by a board that supports another row. The whole is then covered with manure and

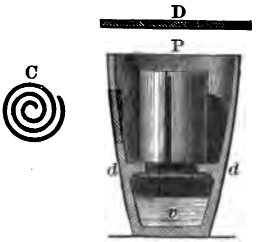


Fig. 117.
Preparation of White Lead.

left for four or five weeks, when most of the lead will have been converted into carbonate.

The exact nature of the reaction is not altogether understood, but it is probable that the heat of the dung volatilizing the vinegar, a basic acetate of lead is formed, which is decomposed by the carbonic acid given off from the rotting mass, and lead carbonate is formed.

On its removal from the pots the carbonate is carefully ground, and obtained in a fine powder by levigation; that is, the ground material is mixed with water, and run successively into a number of large tanks. It remains in the first tank only long enough to permit the heavier particles to settle; it is then run off successively into a second, third, and fourth tank. By these successive settlings the ground material is separated into various grades of fineness, the last tank containing the finest particles.

253. Characteristics of Lead Salts.—The salts of lead have a sweet, astringent taste, and are all very poisonous. Lead acts as a cumulative poison; that is, it produces serious effects when taken in small doses for a considerable time. The disease known as painters' colic is due to the gradual accumulation of lead in the system. Cases of lead-poisoning are often due to the drinking-water dissolving small quantities from the lead-pipes through which it runs.

The soluble sulphates, such as Epsom and Glauber's salts, are antidotes for large doses of lead. Potassium iodide is often employed for gradually removing the lead from the system in chronic cases.

Hydrogen sulphide and ammonium sulphide give a black precipitate with any soluble lead salt. Sulphuric acid gives a white precipitate even with very dilute solutions. Potassium chromate gives a precipitate of yellow chromate.

By heating a lead salt on charcoal with sodium carbonate, in the reducing-flame of a blowpipe, a globule of malleable lead is obtained.

Experiment 74.—Paint any design on a large sheet of white paper with solution of lead acetate. Moisten the paper; and while the design is still invisible, expose it to hydrogen sulphide gas, and the design will immediately appear in black lead sulphide.

SYLLABUS.

Barium, strontium, and calcium are called the metals of the alkaline earths. They are dyads.

The metals of the alkaline earths decompose water at ordinary temperatures; their oxides form hydrates which are powerfully basic.

Barium occurs naturally as the sulphate, in heavy spar, and as the carbonate, in witherite. It may be obtained in the metallic state by electrical decomposition of the fused chloride.

Metallic barium has a silver-white lustre, and possesses so strong an affinity for oxygen that it readily decomposes cold water.

Barium monoxide combines with water and forms barium hydrate. Baryta water is a solution of barium hydrate in water.

Barium sulphide is formed by roasting heavy spar with coal and a little starch. It yields, when treated with different acids, their corresponding barium salts.

Barium chloride is formed by decomposing the sulphide by hydrochloric acid. Artificial barium sulphate may be similarly prepared by the action of sulphuric acid.

Barium nitrate is obtained by the action of nitric acid on the sulphide. It is used in the manufacture of a green fire for fireworks.

The salts of barium are all poisonous; they are readily detected by the dense white insoluble precipitate they give with dilute sulphuric acid. They impart a yellowish-green color to flame.

Strontium occurs naturally as celestine, or the crystallized sulphate, and as strontianite, or the carbonate.

Metallic strontium is obtained by electrically decomposing the fused chloride. It is of a pale yellow color, and burns in the air with a beautiful crimson flame.

Strontium monoxide, like the corresponding barium oxide, forms, with water, a hydrate which possesses caustic properties; its aqueous solution is called strontia water.

Strontium nitrate is prepared by decomposing the sulphide by nitric acid. It is used in fireworks to produce a red fire.

Strontium carbonate is prepared by precipitating any soluble salt of strontium by a soluble carbonate. Strontium sulphate may be similarly prepared by precipitating a strontium salt by a soluble sulphate.

The strontium salts may be detected by the magnificent crimson color they impart to flame. They are not poisonous, but have a disagreeable taste.

Calcium occurs abundantly and widely distributed in nature. Its principal source is the carbonate, or limestone.

Metallic calcium may be prepared by decomposing the fused chloride by electricity. It is a yellow metal with a silvery-golden lustre, and is slightly malleable. It decomposes water when thrown on it, forming calcium hydrate.

Calcium oxide is obtained by calcining limestone. It is commonly known as quicklime. Thrown into water it swells, emits heat, and crumbles into a white powder, which is the hydrate.

Lime is very refractory; it is employed in connection with the oxyhydrogen blowpipe flame as the calcium light.

Quicklime, exposed to the air, absorbs water and carbonic acid gas, and becomes changed into a white powder. This is called air-slaking.

Lime is more soluble in cold water than in hot water.

Ordinary mortar consists of slaked lime mixed with from three to four parts of sharp sand. Exposed to the air it hardens; both by the absorption of carbonic acid gas, which converts the hydrate into carbonate, and, finally, by the combination of the exterior of the grains of sand with the lime, as a hydrated calcium silicate.

Hydraulic mortars contain finely-divided silica, or clay mixed with the lime. They possess the valuable power of hardening under water.

Calcium chloride is produced by the action of hydrochloric acid on marble. Its crystals contain six molecules of water. When these are driven off by heat and the residue fused, it forms the fused calcium chloride, much used for drying-gases.

Calcium fluoride, or fluor-spar, is the main source of fluorine.

Calcium carbonate occurs naturally in a variety of forms, viz.: as limestone, marble, chalk, calcspar, and arragonite.

Calcium carbonate is freely soluble in water containing carbonic acid.

A hard water is one containing lime in solution.

Hard water will not form a lather with soap until all the lime is precipitated in the form of an insoluble lime-soap.

The scale in steam-boilers is due to the lime deposited from the water evaporated in them.

Calcium sulphate, when crystallized, contains two molecules of water. When these are expelled by heat, a substance is formed, known as plaster of Paris, which, when mixed with water, again combines with two molecules, and hardens or sets.

Chlorinated lime, or bleaching powder, is formed by passing chlorine over well-slaked lime. It is used in large quantities for bleaching.

Calcium phosphate occurs in bones. It is used as a fertilizer.

The salts of calcium are colorless; they give no precipitate with hydrogen sulphide or ammonium sulphide, and give a white precipitate with oxalic acid. They impart a greenish-yellow color to flame.

The principal ore of lead is the sulphide, or galena. Metallic lead is extracted from this ore by roasting, and then heating the partially-oxidized mass in a closed furnace.

Metallic lead is a bluish-white metal, that is slightly ductile and malleable, and tarnishes on exposure to air and moisture. It is largely used for shot, bullets, lead-pipe, sheet-lead, and for the manufacture of white lead.

When melted lead is exposed to a current of air, a yellowish amorphous powder called massicot is formed, if the temperature be not too high; otherwise, the oxide melts, and forms a red crystalline mass, called litharge.

Minium, or red lead, is formed by prolonged heating of massicot in a reverberatory furnace, at a temperature too low for fusion. It has a scarlet color, and is crystalline and granular. It is used for a paint; in the manufacture of flint glass, and as a glaze for earthenware.

The oxychloride of lead is obtained by precipitating the chloride in water containing lime. It is extensively used as a white paint.

Lead chromate is used as a yellow paint. It is obtained by adding potassium chromate to a lead salt.

Lead iodide is also used as a yellow paint. It is formed by precipitating a lead salt by potassium iodide.

Lead nitrate is prepared by dissolving litharge in hot dilute nitric acid. It is used in calico-printing and in dyeing.

Lead carbonate, or white lead, is manufactured extensively by the Dutch process—by placing lead in pots containing vinegar, and surrounding them with rotting manure.

The salts of lead are very poisonous; they act on the system as a cumulative poison.

Lead gives a black precipitate with hydrogen sulphide or ammonium sulphide, and a yellow precipitate with potassium chromate.

QUESTIONS FOR REVIEW.

Name the metals of the alkaline earths. Name some of the properties of these metals.

How does barium occur in nature? How may it be obtained in a metallic state? Describe its properties.

Write the chemical formulæ for the oxides and the hydrate of barium. What is baryta water?

How is barium sulphide prepared? Why is it so useful to the chemist?

Describe the manner in which a luminous paint may be produced from barium salts.

How is barium chloride prepared? Write its chemical formula. Describe its properties.

How is barium sulphate prepared? What are its properties? For what is it used?

Write the chemical formula for barium nitrate. How is green fire prepared? How is barium carbonate prepared? For what is it used?

Describe the characteristics of the barium salts.

In what form does strontium occur in nature? Describe the properties of metallic strontium. Write the chemical formulæ for the oxides and hydrate of strontium.

How is strontium nitrate prepared? Describe the preparation of red fire.

Write the chemical formulæ for strontium carbonate, sulphate, and chloride. How are each of these prepared?

Describe the characteristics of the strontium salts.

What is the principal source of calcium? How may it be obtained in a metallic state? What are its properties?

How is calcium oxide prepared? Describe the phenomena attending the slaking of lime. What is air-slaking? How is lime-water prepared?

Describe the manner in which mortar is made. To what is the hardening or setting of mortar due? How are hydraulic mortars made?

Define fat lime; poor lime; cements.

How is fused calcium chloride prepared? For what is it principally used? Write the formula for the crystalline calcium chloride.

Describe the manner in which a luminous calcium paint is produced.

Define hard water; soft water; boiler scale; travertine.

How is plaster of Paris prepared from native gypsum? For what purposes is it employed? Write the chemical formula for gypsum.

How is chlorinated lime prepared? For what is it employed?

Describe the characteristics of the salts of lime.

Describe in full the manner in which lead is extracted from its sulphide. Write the reactions that occur when the furnace employed for this purpose is closed.

Describe the properties of metallic lead. For what purposes is lead employed?

Distinguish between massicot and litharge. How is red lead prepared? For what purposes is it employed?

Write the chemical formulæ for the chloride, the oxychloride, and the iodide of lead.

How are the nitrate, the sulphate, and the chromate prepared? What are their properties?

Describe in full the Dutch process for the manufacture of white lead, or lead carbonate. What is believed to be the manner in which the carbonate is produced in this process?

How is the white carbonate of lead prepared for use as a paint? Describe the process known as levigation.

Name some of the characteristics of the lead salts.

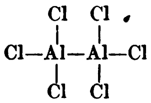
How may lead be eliminated from the system in cases of chronic lead poisoning? What is the antidote for large doses of lead?

CHAPTER XII.

THE METALS OF THE EARTHS.

254. The Quantivalence and Characteristics of the Group.—With the exception of aluminium, the metals of this class are exceedingly rare, and their quantivalence is still quite doubtful. They will therefore be considered here under one group, although the quantivalence of some of them, as, for example, aluminium, appears to be tetradic.

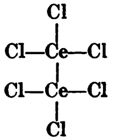
The apparent quantivalence of an element is frequently different from its real quantivalence. Thus, Al_2Cl_6 might seem to indicate aluminium as a triad; but the molecular formula is probably



$$\begin{array}{ccccccc} & & \mathrm{Cl} & & \mathrm{Cl} & & \\ & & | & & | & & \\ \mathrm{Cl} & - & \mathrm{Al} & - & \mathrm{Al} & - & \mathrm{Cl} \\ & & | & & | & & \\ & & \mathrm{Cl} & & \mathrm{Cl} & & \end{array}$$

in which it is a tetrad.

So also cerium and didymium form chlorides which are probably Ce_2Cl_6 and Di_2Cl_6, but the metals probably tetrads. Thus,



$$\begin{array}{ccccc} & & \mathrm{Cl} & & \\ & & | & & \\ \mathrm{Cl} & - & \mathrm{Ce} & - & \mathrm{Cl} \\ & & | & & \\ \mathrm{Cl} & - & \mathrm{Ce} & - & \mathrm{Cl} \\ & & | & & \\ & & \mathrm{Cl} & & \end{array}$$

The metals of the earth possess the following general characteristics, viz.: their oxides are white, are insoluble in water, and cannot be reduced to the metallic state by either carbon or hydrogen.

◆

ALUMINIUM.

Al = 27.5. Sp. Gr. = 2.5. Quantivalence = IV. Discovered by Wöhler in 1827.

255. Occurrence and Preparation.—Aluminium, unlike any of the other metals of this group, is very abundantly and widely diffused in nature, being only excelled in abundance by oxygen and silicon. It occurs in combination in a great variety of minerals, especially the silicates; the principal of these is *feldspar*, an important constituent of granite, gneiss, and most of the primitive rocks. Clay is formed by the decomposition of feldspar.

Metallic aluminium is now prepared on a large scale by exposing a mixture of the double chloride of aluminium and sodium, metallic sodium, and cryolite to bright redness, in a reverberatory furnace. The metal collects on the hearth of the furnace, from which it is cast into moulds.

Metallic aluminium possesses a tin-white color, and can take a high metallic polish. It is both ductile and malleable, and can be drawn into fine wire or hammered into thin leaf. It is elastic and sonorous, and of about the same hardness as silver; it is a good conductor of heat and electricity, and is no heavier than ordinary glass. When pure it does not oxidize at ordinary temperatures, and is scarcely acted on by nitric or sulphuric acids. Hydrochloric acid, or boiling solutions of potassium or sodium hydrates, rapidly dissolve it.

The valuable properties possessed by this metal have caused it, of late years, to be employed for a great variety of purposes; and its manufacture is steadily increasing. Its ores are cheap and abundant; but the metallic sodium needed in its preparation makes its cost as yet comparatively high.

256. Alloys of Aluminium.—Aluminium forms alloys with a number of metals; that with ten per cent. of copper is called *aluminium-bronze*, and has the appearance of gold. This alloy is malleable, and affords excellent castings. It has a tenacity about equal to steel, and, like it, is capable of taking a high polish. Moreover, it is comparatively unalterable in ordinary air. The only obstacle to the general introduction of this alloy is the high price of aluminium. When aluminium is alloyed with ten per cent. of silver an excellent alloy is formed, almost unalterable in air.

257. Aluminium Oxide, Al_2O_3, or *alumina*, occurs in nature in a variety of crystalline forms, much prized as gems, viz.: as the *sapphire*, a rich blue precious stone; the *ruby*, a deep red precious stone; and *corundum*, a stone much prized on account of its extreme hardness, being excelled in this property only by the diamond. The opaque variety of corundum is called *emery*, and is much employed for grinding and polishing glass, etc.

Aluminium oxide may be obtained artificially in a hydrated state by precipitating it from a solution of alum, by the addition of ammonium carbonate. So prepared, it occurs as a gelatinous precipitate, readily soluble in potassium hydrate.

Aluminium oxide may be obtained in the anhydrous state by the action of heat on the hydrated oxide. Anhydrous alumina is very refractory, requiring the heat of the oxyhydrogen blowpipe flame to fuse it.

Aluminium oxide sometimes acts the part of a weak acid, forming a class of salts with powerful bases, called the aluminates.

258. Aluminium Chloride, Al_2Cl_6, is obtained by heating a mixture of alumina and charcoal in a current of chlorine. Thus,

$$\underset{\text{Alumina}}{Al_2O_3} + \underset{\text{Carbon}}{3C} + \underset{\text{Chlorine}}{Cl_6} = \underset{\text{Carbon Monoxide}}{3CO} + \underset{\text{Aluminium Chloride.}}{Al_2Cl_6}$$

Pure aluminium chloride is a white crystalline substance. It forms, with sodium, a double salt, $Al_2Cl_6,2NaCl$, much used in the manufacture of aluminium.

Aluminium bromide, Al_2Br_6, *aluminium iodide*, Al_2I_6, and *aluminium fluoride*, Al_2F_6, also exist.

259. Aluminium Sulphate, $Al_2(SO_4)_3$, may be obtained by the action of sulphuric acid on aluminium hydrate. It is prepared commercially in large quantities by the action of sulphuric acid on a clay containing as little iron as possible. The clay is previously roasted for the double purpose of rendering the iron insoluble, and the clay more soluble. The clear liquid that remains on the settling of the mass after its treatment with sulphuric acid, yields, on evaporation, a soft mass of aluminium sulphate, known commercially as *concentrated alum.* This is extensively employed to increase the weight of paper, and as a mordant (a substance employed to fix colors used in dyeing). An impure variety is called *alum-cake.*

Experiment 75.—Boil a cotton rag in a solution of aluminium acetate obtained by adding sugar of lead to a solution of alum and filtering the solution. Now dip the cloth in a solution of logwood, and the dye is at once firmly fixed in its fibre.

260. Alum, $Al_2(SO_4)_3+K_2SO_4+24H_2O$. Alum is the general name given to a class of compounds formed by the combination of aluminium sulphate with any of the alkaline sulphates.

Alum is prepared commercially on a large scale by gently roasting a pyritous clay and exposing it to the air, by which means it is converted into aluminium and ferrous sulphate. The mass is treated with water, and after concentration by heat, is mixed with potassium chloride, which acts on the ferrous sulphate, producing ferrous chloride and potassium sulphate. The aluminium and potassium sulphates then combine and form alum, which is separated from the soluble iron salt by successive crystallizations.

Potassium alum crystallizes in colorless octahedral crystals, which have a sweetish, astringent taste, and are readily soluble in water, the solution reddening litmus paper slightly. On being heated they lose their water of crystallization and form *burnt alum.*

Experiment 76.—Dissolve some alum in rather more than twice its weight of hot water, and set the solution aside. Beautiful octahedral crystals will gradually separate from the solution, and will attach themselves to any object placed in the solution.

Alum is employed in large quantities in the arts, in dyeing, in calico printing, in the manufacture of paper, in tanning, in the hardening and whitening of tallow, for rendering fabrics partly incombustible, in medicine, and for a variety of other purposes.

The potassium, or the aluminium, or both, may be replaced by a number of substances, producing a large class of bodies having the properties of alum and isomorphous with it. The following table contains the most important of these alums. On account of its greater cheapness, ammonium alum has now almost replaced potassium alum in the arts and in commerce.

Sodium alum = $Al_2(SO_4)_3 + Na_2SO_4 + 24H_2O$.
Ammonium alum = $Al_2(SO_4)_3 + (NH_4)_2SO_4 + 24H_2O$.
Thallium alum = $Al_2(SO_4)_3 + Tl_2SO_4 + 24H_2O$.
Cæsium alum = $Al_2(SO_4)_3 + Cs_2SO_4 + 24H_2O$.
Rubidium alum = $Al_2(SO_4)_3 + Rb_2SO_4 + 24H_2O$.
Lithium alum = $Al_2(SO_4)_3 + Li_2SO_4 + 24H_2O$.
Silver alum = $Al_2(SO_4)_3 + Ag_2SO_4 + 24H_2O$.
Manganese alum = $Mn_2(SO_4)_3 + K_2SO_4 + 24H_2O$.
Iron alum = $Fe_2(SO_4)_3 + K_2SO_4 + 24H_2O$.
Chromium alum = $Cr_2(SO_4)_3 + K_2SO_4 + 24H_2O$.

261. Aluminium Silicates.—The natural silicates, both anhydrous and hydrated, form an exceedingly large class of mineral substances.

The following are but a few of these silicates, viz., *pyroxene; beryl; mica; scapolite; feldspar* and its varieties, such as *albite, orthoclase, oligoclase, and labradorite, tourmaline, euclase*, etc. *Topaz*, $Al_2SiO_4Fe_2$; *beryl*, $Be_3Al_2Si_6O_8$; *noble garnet*, $(MgFe)_3Al_2Si_3O_2$, and *lapis lazuli*, are among the precious stones belonging to this class.

Ultramarine, a deep blue coloring matter, used for a paint, for coloring paper, etc., is manufactured in immense quantities by heating together a mixture containing soft clay, charcoal, sulphur, soda, and Glauber's salts.

Clay is a hydrated aluminium silicate. Its composition varies with the feldspar from which it has been derived.

Marl is a mixture of clay and chalk.

262. Porcelain and Pottery are produced by the action of a high heat on a mixture containing clay. Their basis is aluminium silicate. This silicate has to be mixed with sand, powdered flint, and other materials to prevent shrinkage and consequent cracking during baking. To these is added some readily fusible material, which undergoes vitrification and further binds the ingredients together. After baking in a kiln the articles are glazed, in order to remove the coarse, rough surface, and to render the ware impermeable to ordinary liquids.

Porcelain or *china* differs from ordinary earthenware mainly in that the materials are carefully selected and are free from iron or other color-producing substances. Kaolin, feldspar, chalk, and pure sand make an excellent ware. This ware is glazed with a mixture of quartz and feldspar.

Stoneware is a variety of porcelain, with less pure materials, and consequently more or less colored. It is usually glazed by throwing salt on the incandescent ware, by which a fusible double silicate of aluminium and sodium is formed on the surface. *Wedgewood* ware is fine stoneware.

Common earthenware is made of still poorer clay and is coated with lead glaze.

Bricks, tiles, flower-pots, etc., are made from the coarsest varieties of clay.

263. Characteristics of the Compounds of Aluminium.—The soluble aluminium salts are mostly colorless, possess a sweet, astringent taste, and redden litmus paper slightly.

They yield a bulky gelatinous precipitate of hydrate of alumina, with ammonium sulphide, ammonia, and the alkaline carbonates.

By adding potassium sulphate and excess of sulphuric acid to solutions containing aluminium, octahedral crystals of potassium alum are obtained.

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GLUCINUM OR BERYLLIUM.

Gl = 9.5. Sp. Gr. = 2.1. Discovered by Vauquelin in 1798.

264. Occurrence and Properties.—This metal occurs in various silicates, principally in the mineral *beryl*. It is obtained in the metallic state by the action of melted sodium on the vapor of the chloride.

Metallic glucinum is a white malleable metal, rather more fusible than silver. It is soluble in dilute acids when in a finely divided state.

Glucinum oxide, GlO, is obtained from the mineral beryl. It is an amorphous white powder, insoluble in water, but soluble in dilute acids. It resembles alumina in its physical properties, and, like it, is soluble in potassium or sodium hydrate.

Glucinum chloride, $GlCl_2$, is obtained by dissolving the metal in hydrochloric acid. Sulphates, nitrates, phosphates, and carbonates of glucinum exist.

The name glucinum is derived from γλυκός, sweet, on account of the peculiar sweet taste of all its salts.

THORIUM.

Th = 234. Sp. Gr. = 7.7. Discovered by Berzelius in 1828.

265. Occurrence and Properties.—Thorium is a very rare metal, that occurs in *thorite*, *euxinite*, and a few other minerals. It is obtained in the metallic state by the action of sodium on the chloride.

Metallic thorium has an iron-gray lustre. When heated in the air it burns with a bright flame. It does not decompose boiling water; is readily soluble in nitric acid, and dissolves with difficulty in hydrochloric acid.

It forms a variety of colorless soluble salts, that have a strong astringent taste.

YTTRIUM.

Y = 92.5. Discovered by Eckeberg in 1797.

266. Occurrence and Properties.—In 1797 Eckeberg discovered the new earth yttria in the mineral *gadolinite*. In 1819 Berzelius showed that this mineral contained the then newly discovered metal, cerium, named from the planetoid

Ceres, then recently discovered. In 1839 Mosander showed that gadolinite contained another new metal, which he named lanthanum, from λανθάνω, I lie hidden. In 1841 the same chemist discovered in this mineral another new metal, which he named didymium, from διδύμος, twins; and in 1843 he found that it contained two more new metals, which he called terbium and erbium, from the terminal letters of the second syllable of Ytterby, where the mineral was found. The separation of these rare metals is a very difficult matter.

Metallic yttrium is obtained by heating the chloride with potassium. It has the color and lustre of iron. It forms an oxide Y_2O_3, a yellowish-white powder; a non-volatile chloride YCl_3; and a number of other salts. Its presence is best distinguished by the use of the spectroscope.

ERBIUM.

Er = 169. Discovered by Mosander in 1843.

267. Occurrence and Properties.—This rare metal occurs in the mineral *gadolinite* and in *samarskite.* It has not yet been obtained in the metallic state. Its oxide, Er_2O_3, is a white powder. The presence of the salts of this metal is detected by the use of the spectroscope.

TERBIUM.

Tr = 148.5. Discovered by Mosander in 1843.

268. Occurrence and Properties.—This rare metal occurs in *gadolinite* and in *samarskite.* It has not yet been obtained in the metallic state. The oxide, Tr_2O_3, is a dark, orange-yellow powder. The sulphate, $Tr_2(SO_4)_3+8H_2O$, occurs in colorless crystals that are isomorphous with the corresponding salts of yttrium and erbium.

CERIUM.

Ce = 141.2. Sp. Gr. = 6.7. Discovered by Klaproth in 1803.

269. Occurrence and Properties.—This rare metal occurs in the minerals *cerite, orthite, gadolinite,* etc. It may be obtained in the metallic state by the action of sodium on the chloride.

Metallic cerium resembles iron both in color and lustre; it is malleable, and, when heated, ductile. In moist air it oxidizes, becoming first yellow, then blue, and finally green.

This metal burns in the air more brilliantly than magnesium.

Cerium forms two oxides, Ce_2O_3, of a bluish-green color, and CeO_2, of a pale straw color. These form two series of salts, viz., the cerous and the ceric.

Sodium hypochlorite, added to a colorless cerium salt, gives a characteristic red precipitate.

The presence of the salts of cerium can be best detected by the use of the spectroscope.

LANTHANUM.

La = 139. Sp. Gr. = 6.16. Discovered by Mosander in 1839.

270. Occurrence and Properties.—This rare metal occurs in *gadolinite* and *cerite.* It may be obtained in the metallic state by the action of potassium on the chloride.

Metallic lanthanum has an iron-gray color, and can take a high polish. It is slightly malleable, but not ductile. Exposed to the air, it is rapidly covered with a steel-blue coating of oxide. It is slowly oxidized by cold water.

Lanthanum oxide, La_2O_3, is a white powder that, thrown on water, forms a hydroxide. It forms a number of salts, that have an astringent sweetish taste.

The presence of lanthanum can be best detected by the use of the spectroscope.

DIDYMIUM.

Di = 147. Sp. Gr. = 6.54. Discovered by Mosander in 1841.

271. Occurrence and Properties.—This rare metal occurs in *cerite* and *gadolinite*. It is obtained in the metallic state from the chloride like the preceding metals. It resembles cerium, but has a darker color and a slight tinge of yellow. On exposure to the air, it becomes covered with a layer of yellow oxide, and burns with a brilliant light when in a state of fine division.

Didymium oxide, Di_2O_3, is of an impure blue color. Didymium forms a number of salts that possess a sweetish taste.

ZIRCONIUM.

Zr = 90. Sp. Gr. = about 4.15. Discovered by Klaproth in 1789.

272. Occurrence and Properties.— Zirconium is a rare metal that occurs in the minerals *zircon*, *hyacinth*, and a few others. It has been obtained in the form of brittle crystalline scales, containing one per cent. of aluminium and a trace of silicon; their sp. gr. = 4.15. These scales are not attacked by ordinary acids, and require the heat of the oxyhydrogen flame to burn in the air.

Zirconium forms but one oxide, ZrO_2, which unites with both acids and bases, forming a class of salts called *zirconates*. It combines with acids, producing various salts of zirconium. The presence of zirconium is most readily detected by means of the spectroscope.

SYLLABUS.

The metals of the earths are aluminium, glucinum or beryllium, thorium, yttrium, erbium, terbium, cerium, lanthanum, didymium, and zirconium.

With the exception of aluminium, the metals of the earths are exceedingly rare; their quantivalence is not accurately known. They are apparently either dyads or tetrads.

Aluminium is the third most abundant of the elements. It occurs naturally in a vast variety of minerals; principally in various silicates, the most important of which is feldspar, which, by its decomposition, produces clay.

Metallic aluminium is prepared on a large scale by the action of heat, in a reverberatory furnace, on a mixture of the double chloride of aluminium and sodium, metallic sodium and cryolite.

Metallic aluminium is a metal of a tin-white color, that possesses a variety of properties that eminently fit it for extended use in the arts. It can take a high polish; is both ductile and malleable; is not oxidized at ordinary temperatures, nor appreciably attacked by nitric or sulphuric acids; is no heavier than ordinary glass; conducts both heat and electricity, and possesses considerable elasticity. Its high cost alone prevents its more extended use.

Aluminium bronze is an alloy of aluminium with ten per cent. of copper. It has the appearance of standard gold, and nearly the tenacity of steel.

Aluminium oxide, or alumina, occurs in nature crystallized as the sapphire, the ruby, and corundum. The latter is excelled in hardness only by the diamond. An opaque variety of corundum is called emery.

Alumina may be obtained artificially, in a hydrated condition, by precipitating a solution of alum by ammonium carbonate; and anhydrous, by subjecting the precipitate to the action of heat.

Aluminium chloride is obtained by heating alumina and charcoal in a current of chlorine.

Aluminium sulphate is prepared commercially by the action of sulphuric acid on pure clay. It is known commercially as concentrated alum. An impure variety is called alum-cake.

Alum is a general name given to a variety of salts containing aluminium sulphate combined with some other sulphate. Ordinary alum is a double sulphate of aluminium and potassium, or aluminium and ammonium. It is prepared commercially by roasting a clay rich in iron pyrites, and so converting it into aluminium and ferrous sulphates, and afterwards treating with water and adding potassium chloride.

Alum crystallizes in colorless octahedral crystals, that have a sweetish, astringent taste, and are readily soluble in water. Alum is extensively employed in the arts in dyeing, in calico-printing, in the manufacture of paper, in tanning, and for a variety of other purposes.

The potassium or the aluminium, or both, may be replaced by other isomorphous substances, thus giving rise to a great variety of alums.

Topaz, beryl, noble garnet, and lapis lazuli are among the precious stones belonging to the natural silicates.

Ultramarine is an artificial silicate, of a magnificent blue color, much employed as a pigment, and for coloring paper.

Clay is a hydrated silicate of aluminium. Marl is a mixture of sand and clay.

Porcelain and pottery consist of clay mixed with sand and flint to prevent shrinkage and cracking during baking. After baking, the surface is glazed, in order to render the ware impervious to liquids, and to give it a smooth, glassy surface.

Porcelain or china differs from stoneware mainly in the greater purity of the materials employed in the manufacture of the former. Porcelain is generally glazed by a mixture of quartz and feldspar, while stoneware is generally glazed by throwing common salt over the ware while incandescent.

Earthenware is a still lower grade of ware, and is generally glazed with lead glaze.

Bricks, tiles, flower-pots, etc., are made of the coarsest, commonest clays.

Glucinum, or beryllium, is a rare metal existing in the mineral beryl. It is a white, malleable metal, rather more fusible than silver. It is soluble in dilute acids when in a finely divided state. Its name is derived from γλυκός, sweet, from the peculiar sweet taste of its salts.

Thorium is a rare metal existing in the minerals thorite and euxinite. It has an iron-gray lustre, and burns in the air with a bright flame.

Yttrium, erbium, terbium, cerium, lanthanum, and didymium, are very rare metals, that exist in the minerals gadolinite, cerite. They are obtained in the metallic state by the action of potassium or sodium on their chlorides, and are most readily detected by the use of the spectroscope. They form a variety of salts, of interest mainly on account of their rarity.

Zirconium is a rare metal existing in the mineral zircon. It forms an oxide that possesses both acid and basic properties.

QUESTIONS FOR REVIEW.

Name the metals of the earths. What is believed to be the quantivalence of these metals?

How does aluminium compare with the other elements as regards its abundance in nature? What are its principal mineral sources? How is metallic aluminium prepared commercially?

Describe the properties possessed by aluminium that so eminently fit it for extensive application in the useful arts.

Describe some of the useful alloys of aluminium.

Name some of the natural crystalline forms of aluminium oxide or alumina. How may hydrated and anhydrous alumina be prepared artificially?

Write the reaction for the process generally adopted for obtaining aluminium chloride.

How is aluminium sulphate prepared commercially? What is the composition of concentrated alum? Of alum cake?

Describe the manufacture of ordinary potassium alum. Describe its properties. Name some of the purposes for which it is used in the arts.

Write the chemical formula for ordinary alum. What other alums exist?

Name some of the commonest of the native aluminium silicates. Name some of the precious varieties.

How is ultramarine produced? What is the composition of clay? Of marl?

Describe the composition of porcelain and china. How are these wares glazed? How does earthenware differ from porcelain? What glaze is generally employed for earthenware?

What is the composition of common pottery, and how is it glazed?

From what kinds of clay are bricks, tiles, and flower-pots manufactured?

Describe some of the characteristics of the aluminium salts.

What is the principal natural source of glucinum or beryllium? How is metallic glucinum obtained? What is the origin of the name glucinum?

What is the principal natural source of thorium? Describe some of the properties of metallic thorium.

In what minerals are yttrium, erbium, terbium, cerium, lanthanum, and didymium contained? Which of these metals have been obtained in a pure state? How were they thus obtained?

What is the derivation of the word lanthanum? Of didymium? Of cerium? Of erbium and terbium?

What are the principal natural sources of the rare metal zirconium? What peculiarity does its oxide possess?

CHAPTER XIII.

MAGNESIUM, ZINC, AND CADMIUM.

273. Characteristics of the Group.—The metals of this group are all volatile at high temperatures, and burn with a bright flame when heated in the air. They decompose water at high temperatures, and give off hydrogen from dilute acids. They form but one oxide and one sulphide. Their sulphates are soluble in water.

◆

MAGNESIUM.

Mg = 24. Sp. Gr. = 1.75. Discovered by Davy. First obtained pure by Bussy in 1830.

274. Occurrence and Preparation.—Magnesium occurs abundantly and widely diffused in nature as magnesian limestone, a double carbonate of calcium and magnesium. It also occurs in mineral deposits as the hydrate, carbonate, phosphate, and sulphate, or is found dissolved in the waters of certain springs. Some of its mineral forms are seen in *soapstone*, *talc*, *hornblende*, and *dolomite*.

Magnesium is obtained commercially in a metallic state in large quantities, by the action of metallic sodium on a mixture containing fused magnesium chloride and fluor-spar, in a covered crucible. After the reaction, the metallic globules are separated from the mass, by heating it to redness in a charcoal-lined tube in a current of hydrogen, when the metallic magnesium distils and collects in the cooler parts of the tube.

275. Properties of Metallic Magnesium.—Magnesium is a brilliant, silver-white metal, that melts at a red heat, and volatilizes at a higher temperature. It is unaffected in dry air, and is but slowly oxidized in damp air. It may be rolled into sheets or drawn out into wire. When heated in the air, it burns with great brilliancy, forming a white oxide. The light produced by the burning metal is sometimes employed for taking photographs at night and in dark places, but is now generally displaced by the electric light.

276. Magnesium Oxide and Chloride.—*Magnesium oxide,* MgO, is formed by burning the metal in air. It is prepared commercially by calcining the carbonate, by which means it is obtained as a white and very light powder, known in medicine as *calcined magnesia.* It is nearly insoluble in water, and is consequently tasteless. It fuses in the flame of the oxyhydrogen blowpipe, solidifying into a solid sufficiently hard to scratch glass.

Magnesium hydrate, $Mg(OH)_2$, is the white precipitate formed by adding a solution of potassium hydrate to a soluble magnesium salt.

Magnesium chloride, $MgCl_2$, occurs in all ocean water, and in the waters of many brines and other mineral springs, from which latter it is obtained by concentrating their solutions. It is thus obtained as a crystalline salt, having the composition $MgCl_2+6H_2O$. It has a bitter taste, and is largely employed as a dressing for cotton goods. It forms double crystalline salts with the alkaline chlorides.

Magnesium bromide, $MgBr_2$, and *magnesium iodide,* MgI_2, occur in ocean water.

277. Magnesium Carbonate, and Magnesium Sulphate.—*Magnesium carbonate,* $MgCO_3$, occurs crystallized in nature as the mineral *magnesite.* It is soluble in water containing carbonic acid. The *white magnesia* of the apothecary is obtained by precipitating Epsom salts, or magnesium sulphate, by sodium carbonate and drying the precipitate.

Magnesium sulphate, $MgSO_4+7H_2O$, or Epsom salts, occurs in various mineral waters, especially at Epsom, England. It is also an ingredient in all ocean water. It crystallizes in rhombic prisms, Fig. 118. Magnesium sulphate is used in medicine as a purgative; as a dressing for cotton goods; in dyeing, and as a manure. It is produced artificially on a large scale from the magnesium minerals. It has a disagreeable, salty, bitter taste.

Magnesium sulphate forms a series of double salts with the alkaline sulphates.

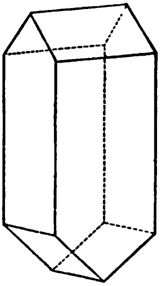


Fig. 118. Epsom Salts.

278. Characteristics of the Magnesium Salts.—The magnesium salts do not impart any appreciable color to a non-luminous flame. Their spectrum, produced by an electric spark, gives a number of very characteristic lines.

They give no precipitate with hydrogen or ammonium sulphides, but give a white, flocculent precipitate with sodium carbonate.

The addition of sodium phosphate and ammonium hydrate to a solution of a magnesium salt yields, after a short time, a characteristic crystalline precipitate.

* * *

ZINC.

Zn = 65.2. Sp. Gr. = 6.9. Melts at 773° F.

279. Occurrence and Metallurgy.—The principal ores of zinc are *zinc blende*, ZnS; *calamine*, $Zn_2SiO_4+H_2O$, and *smithsonite*, $ZnCO_3$.

In order to extract the zinc, the ores are first roasted, by which the carbonic acid or water is driven off, or the sulphide converted into an oxide (care being taken to avoid converting the sulphide into sulphate, which is difficult to reduce). The roasted ore is then powdered and mixed with charcoal, and heated to redness in suitably arranged furnaces. Carbonic acid is formed and metallic zinc given off in a volatile state.

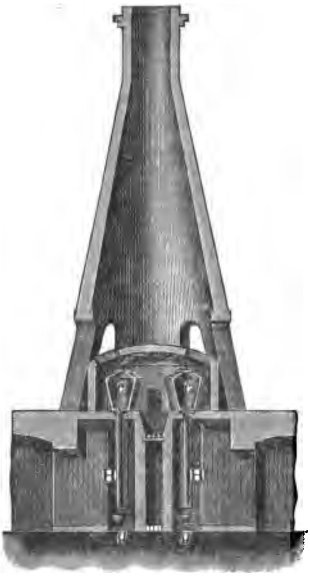


Fig. 119.—Distillation per Descendum.

This reduction is accomplished in various ways. In the process called *distillation per descendum*, the mixture of roasted ore and coal is placed in crucibles, *c*, *c*, Fig. 119, closed at the top but provided with an opening at the bottom, closed by a wooden plug, and an iron tube, H H, which fits close to the opening. The wooden plug, converted by the heat into charcoal, permits the vapor of the zinc to pass through it, but prevents the passage of the solids in the crucible. The zinc vapor passes through the tubes H, H, which act as condensers, and collects in the vessels *g g*, placed below them. The zinc is remelted and cast into commercial slabs.

In the *Silesian process*, which is now generally adopted, clay retorts, or muffles, M M, are suitably arranged in a reverberatory furnace, Fig. 120, and filled with the roasted ore and carbon. The zinc vapor passes through a bent clay pipe, A, and is condensed in an iron receiver, O. Commercial zinc is generally contaminated with lead, iron, and carbon, and sometimes with arsenic.

280. Properties of Zinc.—Metallic zinc has a bluish-white color and a brilliant laminated or crystalline fracture. Between 212° F. and 300° F. it possesses considerable ductility and malleability, but is very brittle at about 400° F.

Commercial zinc readily dissolves in hydrochloric and sulphuric acids, with the evolution of hydrogen. Its solubility is due to the voltaic action produced by small particles of carbon, lead, or iron. When pure it is dissolved, but very slowly. When in thin sheets, as in spinnings, it burns readily in the air with a blue flame.

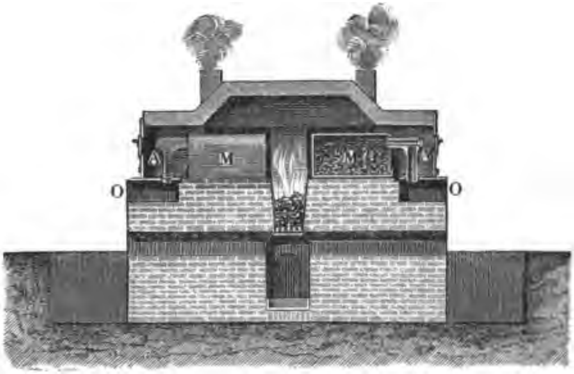


Fig. 120.—Silesian Process.

Metallic zinc is largely used in the form of sheets; in the manufacture of brass; for electrical batteries, and for preserving iron from rust, by dipping it in a bath of molten zinc, producing the so-called *galvanized iron.*

281. Zinc Oxide, ZnO, is formed when zinc is burned in the air. It is prepared on a large scale as *zinc white,* by burning the vapors of distilled zinc in a current of air, and allowing the oxide to condense in large chambers. It is extensively used as a white paint. It is better adapted than lead for a white paint in all situations where sulphur gases are given off, since the lead sulphide which is formed on the surface of the paint is black, while the zinc sulphide is white.

Zinc hydrate, $Zn(OH)_2$, is obtained by adding potassium hydrate to a solution of any zinc salt; thus:

$$\underset{\text{Zinc Sulphate}}{ZnSO_4} + \underset{\text{Potassium Hydrate}}{2KOH} = \underset{\text{Potassium Sulphate}}{K_2SO_4} + \underset{\text{Zinc Hydrate.}}{Zn(OH)_2}$$

282. Zinc Chloride, $ZnCl_2$, is prepared by dissolving zinc in hydrochloric acid. The concentrated solution forms a syrupy liquid, which has a burning taste and is poisonous. It is employed in surgery as a caustic; is used to prevent decay in animal and vegetable substances; is used as a soldering solution; is employed in the weighting of cotton goods, and for a variety of other purposes.

A concentrated solution of zinc chloride deposits, on standing, colorless octahedral crystals, $ZnCl_2+H_2O$, which are strongly deliquescent.

Zinc bromide, $ZnBr_2$, *zinc iodide*, ZnI_2, and *zinc sulphide*, ZnS, exist.

283. Zinc Sulphate, $ZnSO_4+7H_2O$, or *white vitriol*, may be obtained by suitably roasting blende or zinc sulphide, treating the roasted mass with water, evaporating the solution to dryness, and gently calcining the residue. This decomposes the ferrous sulphate, arising from the iron sulphide always in the blende, into sulphuric acid and insoluble ferric oxide. The zinc sulphate is then extracted from the mass by hot water, which, on cooling, deposits crystals of the sulphate.

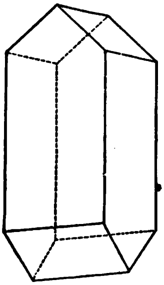


Fig. 121. Zinc Sulphate.

Zinc sulphate is frequently found in the waters of zinc mines, where it is formed by the oxidation of the zinc sulphide.

Zinc sulphate has an astringent, metallic taste. It is used in medicine, as an eye-wash, and in dyeing.

284. Characteristics of Zinc Salts.—Hydrogen and ammonium sulphides throw down a white precipitate of sulphide when added to a neutral soluble salt of zinc.

Potassium and sodium hydrates give white precipitates, soluble in excess of the hydrate.

Potassium ferrocyanide gives a white precipitate.

The salts of zinc, heated in the flame of a blowpipe on charcoal, and then moistened with nitrate of cobalt and again heated, yield a beautiful green color.

CADMIUM.

Cd = 112. Sp. Gr. = 8.66. Discovered by Stromeyer in 1817.

285. Occurrence and Properties.—This metal generally occurs associated with certain zinc ores. During the distillation of zinc from ores containing cadmium, the latter, which is more volatile than the zinc, condenses as a yellowish powder. Its name is derived from the word *cadmies*, a name given to the yellowish-brown powder that condenses during the beginning of the distillation of zinc. This powder consists of a mixture of the oxides of zinc and cadmium.

Metallic cadmium is obtained from this powder by mixing it with charcoal and heating the mixture in iron tubes, when cadmium distils over, slightly alloyed with zinc. This is dissolved in hydrochloric acid, and the cadmium precipitated on a plate of zinc immersed in the solution.

Metallic cadmium has a white lustre and fibrous fracture. When sublimed in a current of hydrogen, it crystallizes in octahedra. It is somewhat harder than tin; can take a high polish, and is both malleable and ductile. It boils at 1580° F., emitting a vapor of a dark yellow color, that, when breathed, causes headache. It readily tarnishes on exposure to the air, and dissolves in dilute sulphuric and hydrochloric acids, replacing the hydrogen.

286. The Compounds of Cadmium.—*Cadmium oxide*, CdO, has a yellowish-brown color, and is formed when the metal burns in the air. Mixed with charcoal it is more readily reduced by heat than zinc oxide.

Cadmium hydrate, $Cd(OH)_2$, is obtained as a white precipitate by adding potassium hydrate to a cadmium salt in solution.

Cadmium chloride, $CdCl_2$, and *cadmium iodide*, CdI_2, are obtained by the action of hydrochloric or hydriodic acids on the metal.

Cadmium sulphide, CdS, occurs naturally as the yellow mineral *greenochite*. It may be obtained artificially by precipitating any soluble cadmium salt by hydrogen sulphide or ammonium sulphide. It is employed by artists as a fine yellow paint.

Cadmium sulphate, $CdSO_4$, is obtained by the action of dilute sulphuric acid on the metal. It yields from its aqueous solution large monoclinic crystals, whose composition is $CdSO_4+8H_2O$. This salt is employed in certain diseases of the eye.

The salts of cadmium yield, with hydrogen sulphide or ammonium sulphide, a characteristic yellow sulphide, distinguished from the yellow sulphides of tin, antimony, and arsenic, by its insolubility in caustic alkalies and ammonium sulphide.

CHAPTER XIV.

MERCURY AND COPPER.

287. Characteristics of the Group.—The metals of this group do not decompose water even at a red heat. They are readily oxidized by nitric acid, and by strong hot sulphuric acid. They form several oxides and several chlorides, and are precipitated in the metallic state from their solutions by a number of metallic substances.

* * *

MERCURY.

Hg = 200. Vapor density = 100. As compared with air, 6.976. Sp. Gravity of liquid = 13.59.

288. Occurrence and Extraction.—Mercury is sometimes found in small quantities in a pure state in nature. Its principal ore is the sulphide, or *cinnabar*. Some of the best known localities of the ore are Almaden, in Spain; Idria, in Austria, and in California.

The metal is extracted from its ore by roasting in furnaces that permit the entrance of a current of air. Under the influence of heat and air, the sulphur is converted into sulphur dioxide, and the mercury volatilized. The fumes are led through suitably arranged chambers, in which the mercury is condensed. Several different arrangements are employed for this purpose. Fig. 122 shows the arrangement adopted at Idria. The fire, F, is placed below a number of furnaces *f*, *f*, resting on one another. These furnaces are in connection on each side with condensing chambers, C, C, C, etc., connected with one another by openings alternately at the top and bottom. Only three of these chambers are shown in the figure on each side of the furnace; generally many more are employed. The condensed metal collects in the bottom of the chambers; it is then filtered through chamois skin, and subsequently purified from the lead, tin, copper, etc., alloyed with it, by careful redistillation. Or it may be purified by digesting it for a number of days with dilute nitric acid, which dissolves the foreign metals.

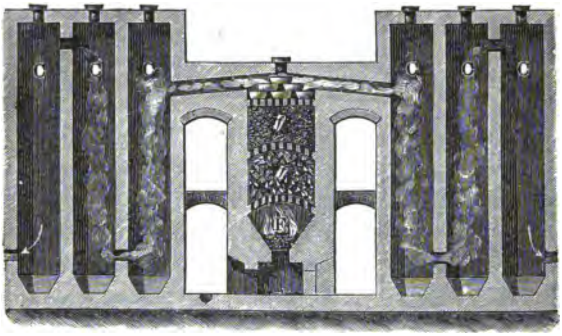


Fig. 122.—Extraction of Mercury.

289. Properties of Mercury.—Pure mercury is a silver-white, mobile liquid, that freezes at —39.2° F., and boils at 662° F., giving off an invisible, transparent vapor. It also slowly evaporates at ordinary temperatures.

Mercury does not oxidize on exposure to the air, but when heated to about 800° F., it becomes changed into the red oxide. It readily combines with chlorine and bromine, and forms amalgams with most of the metals. Hydrochloric acid has no action on the metal, either hot or cold. Concentrated sulphuric acid does not attack it unless heated. Strong nitric acid readily dissolves it.

Pure mercury, when placed in small drops on a smooth board, assumes the shape of small, bright, metallic spheres. When impure, the drops are readily drawn out to a point, and become tarnished by the oxidation of the baser metals.

Mercury is largely employed in the construction of physical and chemical apparatus. It is employed in large quantities in the extraction of gold and silver. Many of its amalgams are employed in gilding and silvering. It is employed in the manufacture of a beautiful pigment called vermilion, and is used to a considerable extent in medicine.

Blue mass, from which blue pills are made, is obtained by rubbing mercury with saccharine or fatty matters, by which means the mercury is obtained in a state of extreme division, partially oxidized. The use of mercury in large doses is to be carefully avoided, as is also its long continued use in small doses, as it is to a certain extent cumulative in its effects on the system, and gives rise to chronic poisoning. So, too, workmen exposed to its fumes are often affected with a nervous disease called *mercurial palsy*.

290. Oxides of Mercury.—Mercury combines with oxygen to form two oxides, viz.: *mercurous oxide*, Hg_2O, and *mercuric oxide*, HgO. These give rise to two classes of salts, viz., the *mercurous salts*, and the *mercuric salts*.

Mercurous oxide, Hg_2O, *sub-oxide*, or *gray oxide of mercury*, is obtained by the action of caustic potash on mercurous chloride, Hg_2Cl_2, or *calomel*. It is an unstable, dark-brown powder.

Mercuric oxide, HgO, *red oxide of mercury*, or *red precipitate*, is prepared commercially by decomposing a mixture of metallic mercury and mercuric nitrate by heat, which produces it in the form of bright, orange-red, crystalline granules. It may also be obtained by precipitating a mercuric salt in solution, by caustic soda. It possesses an alkaline, metallic taste, and is powerfully poisonous. It parts readily with its oxygen, especially to carbon, phosphorus, and sulphur, producing an explosive mixture when heated with the latter.

291. Mercury and Chlorine.—*Mercurous chloride*, Hg_2Cl_2, or *Calomel*, is prepared in a number of ways, one of the best of which is by the action of heat on a mixture of mercurous sulphate and sodium chloride, thus:

$$\underset{\text{Mercurous Sulphate}}{Hg_2SO_4} + \underset{\text{Sodium Chloride}}{2NaCl} = \underset{\text{Mercurous Chloride}}{Hg_2Cl_2} + \underset{\text{Sodium Sulphate.}}{Na_2SO_4}$$

The calomel sublimes, and is collected in compact masses, that have a crystalline structure. When used as a medicine, it is again sublimed, the vapor being condensed in a vessel filled with steam, where it collects in a finely divided form.

Mercurous chloride may also be prepared by precipitating a solution of mercurous nitrate by sodium chloride.

Prepared by the first process, calomel is a heavy, fibrous, crystalline, tasteless mass, insoluble in water. It is much used in medicine, though in smaller doses than formerly. Its specific gravity is 6.58.

Mercuric chloride, $HgCl_2$, or *corrosive sublimate*, is obtained by the action of heat on mercuric sulphate and sodium chloride, thus:

$$\underset{\text{Mercuric Sulphate}}{HgSO_4} + \underset{\text{Sodium Chloride}}{2NaCl} = \underset{\text{Sodium Sulphate}}{Na_2SO_4} + \underset{\text{Mercuric Chloride.}}{HgCl_2}$$

The chloride sublimes, and is condensed in the upper part of the vessel. A small quantity of manganese dioxide added to the mixture prevents the formation of calomel, should the sulphate contain any mercurous salt.

Corrosive sublimate is a heavy, white, crystalline mass, more volatile than calomel. It is soluble in water, has a sharp metallic taste, and is exceedingly poisonous. Its specific gravity = 6.5. When crystallized by sublimation it occurs in octahedra.

This salt is frequently employed as a bug poison. Its antidote is raw white of egg or albumen, with which it forms an insoluble precipitate.

Mercuric chloride forms a number of soluble double-crystallizable salts with other chlorides.

292. Mercury and Sulphur.—Only one sulphide exists, viz., *Mercuric sulphide*, HgS. This occurs native as *cinnabar*. Mercuric sulphide is obtained commercially by the direct combination of the metal with sulphur. The two substances are mixed together in small barrels rotated by machinery, until a dark-brown powder is obtained. This is afterwards sublimed in iron vessels, when the cinnabar collects in heavy, dark-red, fibrous, crystalline masses, having a specific gravity of 8.12.

Vermilion is a rich, scarlet pigment, consisting of the finely-divided sulphide. It is obtained by the action of caustic potash and water on the brown mass produced by the prolonged mixing of mercury and sulphur. It is employed as a pigment by artists, and for coloring sealing-wax.

293. Mercury and Iodine.—*Mercurous iodide*, Hg_2I_2, is an unstable, dark-green powder, obtained by precipitating mercurous nitrate by potassium iodide.

Mercuric iodide, HgI_2, is a scarlet-red substance, obtained by precipitating a solution of corrosive sublimate by potassium iodide, soluble in excess of either liquid. The precipitate is first yellow, but soon changes to a scarlet red. Mercuric iodide is dimorphous. When the red iodide is gently heated it becomes yellow, but may again be converted into the red modification by rubbing it with any hard body.

Experiment 77.—Spread some of the red iodide on a piece of white card-board with a spatula (flat knife). Hold the back of the card over the flame of a spirit lamp or Bunsen burner until the mass becomes yellow. Now rub the yellow mass with the blade of the knife, and it will change into a bright red.

294. Sulphates of Mercury.—*Mercurous sulphate*, Hg_2SO_4, is a white, crystalline powder, obtained by adding sulphuric acid to a solution of mercurous nitrate.

Mercuric sulphate, $HgSO_4$, is a heavy, white, crystalline powder, obtained by heating metallic mercury and sulphuric acid, and removing excess of acid by heating to dryness. The following reaction occurs, viz.:

$$\underset{\text{Mercury}}{Hg} + \underset{\text{Sulphuric Acid}}{2H_2SO_4} = \underset{\text{Water}}{2H_2O} + \underset{\text{Mercuric Sulphate}}{HgSO_4} + \underset{\text{Sulphur Dioxide.}}{SO_2}$$

This salt is sparingly soluble in water. When thrown into an excess of cold water, it forms a basic sulphate, $HgSO_4 + 2HgO$, of a lemon-yellow color, commonly called *turpeth mineral*.

295. Nitrates of Mercury.—*Mercurous nitrate*, $Hg_2(NO_3)_2$, is obtained by the action of cold dilute nitric acid on metallic mercury. It may be obtained in colorless crystals, having the composition $Hg_2(NO_3)_2+2H_2O$.

Mercuric nitrate, $Hg(NO_3)_2$, is obtained by boiling mercury in an excess of nitric acid. The solution, on evaporation, yields large crystals, whose composition is $2Hg(NO_3)_2+Hg_2O$.

When thrown into an excess of cold water, a yellow basic nitrate is produced, whose composition is $Hg(NO_3)_2.2HgO+H_2O$.

296. Characteristics of the Mercury Salts.—Hydrogen and ammonium sulphides yield a black precipitate of the sulphide.

Hydrochloric acid gives a white precipitate with the mercurous salts, but produces no effect on the mercuric salts. This precipitate is blackened by ammonia.

Potassium iodide yields, with mercurous salts, a green precipitate, which, with an excess of the reagent, is changed into gray metallic mercury.

Potassium hydrate gives, with mercuric salts, a yellow precipitate.

All the mercuric salts are decomposed by metallic copper, zinc, or iron, which, when dipped into their solutions, become coated with mercury.

Experiment 78.—Rub a few drops of mercuric nitrate over a copper coin and it will become coated with a bright metallic film of mercury.

◆

COPPER.

Cu = 63.5. Sp. Gr. = 8.94. Melts at 1996° F.

297. Occurrence and Metallurgy.—Copper occurs in the metallic state, in immense deposits, in the United States, in the Lake Superior region. It also occurs in the form of numerous ores, the most important of which are the cuprous oxide, Cu_2O; cupric oxide, CuO; *malachite*, $CuCO_3+Cu(OH)_2$; *azurite*, $2CuCO_3+Cu(OH)_2$; and as various sulphides, that are often associated with iron.

The cuprous oxide and the carbonates are readily reduced by heated charcoal. The other ores require a rather complicated process in order to eliminate the iron and sulphur.

The process generally employed is as follows, viz.: The ore is first placed in a reverberatory furnace, shaped as in Fig. 123, and roasted in such a manner as to change most of the iron sulphide into oxide, leaving the copper sulphide unaltered. The iron oxide is then removed, as a fusible slag, by strongly heating the mass with silicious sand. The copper sulphide is now reduced to oxide, and, finally, this latter is reduced by heat in the presence of carbon. So obtained, the copper is impure, being alloyed with various metals, from which it is separated by various refining processes.

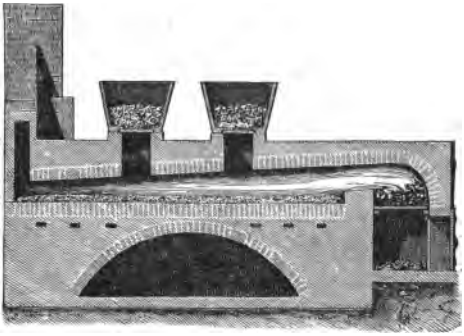


Fig. 123.—Roasting Copper Ore.

The Wet Copper-Extraction Process is employed for the recovery of copper from the refuse of the sulphuric acid works when copper pyrites are roasted. The refuse is calcined with rock-salt, by means of which it is converted into a soluble chloride, from which the copper is precipitated in a metallic state by scrap-iron.

298. Properties and Uses of Metallic Copper.—Pure copper is a tough metal, having a peculiar red color and bright metallic lustre. It is exceedingly malleable and ductile, and possesses a peculiar odor when rubbed by the moistened fingers. It is an excellent conductor of heat; and when perfectly pure is the best conductor of electricity known. Its melting-point is intermediate between gold and silver. It volatilizes at a very high temperature. When heated to a temperature somewhat lower than its melting-point, it becomes so brittle that it can readily be pulverized.

Metallic copper is not affected by dry air; but in the presence of moisture it combines with oxygen and carbon dioxide, forming the well-known greenish substance called *verdigris*. At a high heat, in the presence of sufficient air, it is rapidly converted into the black oxide; if, however, the quantity of air be limited, it is converted into the red oxide. Copper is readily attacked by cold dilute nitric acid, and by boiling sulphuric or hydrochloric acid. It is also readily oxidized in the presence of ammonia.

Metallic copper is produced in immense quantities for the manufacture of wire, especially for electrical purposes. It is made into sheet-copper for various purposes, such as sheathing ships, covering buildings, etc. It is largely used to produce the alloys brass, bronze, and German silver. It is used in very large quantities in the process of electro-plating and electro-metallurgy, by means of which delicately modelled outlines are produced in metallic copper.

299. The Oxides of Copper.—The most important oxides of copper are the cuprous and the cupric.

Cuprous oxide, Cu_2O, occurs native in *cuprite* or red copper ore. It may be obtained artificially as a bright red crystalline precipitate, by boiling copper acetate with glucose. It may be obtained as a yellow hydrate, by precipitating cuprous chloride by caustic potash. Its principal use is in coloring glass a deep red.

Cupric oxide, CuO, occurs native in *melaconite*, or black oxide of copper. It may be obtained artificially by gently heating the nitrate or the carbonate. When heated in the presence of hydrogen or carbon compounds it is reduced, producing water and carbon dioxide. It is, therefore, largely used in the ultimate analysis of organic compounds. It imparts to glass a beautiful green color. Caustic potash precipitates a solution of a cupric salt, in the form of a light blue hydrate, having the composition $Cu(OH)_2$.

300. Sulphides and Chlorides of Copper.—*Cuprous sulphide*, Cu_2S, occurs in nature as *copper glance.* It may be obtained artificially by burning copper in sulphur vapor.

Experiment 79.—Throw some copper filings or turnings into a small test-tube, in which sulphur is boiling. A bright glow takes place from the formation of the cuprous sulphide.

Cupric sulphide, CuS, occurs native in indigo copper. It may be obtained artificially by precipitating any copper salt by hydrogen sulphide.

301. The Chlorides of Copper.—*Cuprous chloride*, Cu_2Cl_2, occurs native as *atacamite.* It may be obtained artificially by the action of aqua regia on metallic copper. The brown liquid so produced gives a white crystalline deposit of cuprous chloride when thrown into water. It is insoluble in water, but dissolves in ammonium hydrate, producing a liquid that readily absorbs carbon monoxide. It also dissolves in hydrochloric acid, and produces a solution that absorbs oxygen on exposure to the air, producing a pigment known as *Brunswick green.*

Cupric chloride, $CuCl_2$, is obtained by dissolving cupric oxide in hydrochloric acid. It forms a deep green solution, that when dilute, is of a blue color.

302. Cupric Sulphate, $CuSO_4+5H_2O$. Copper sulphate, or *blue vitriol*, is obtained commercially in a variety of ways. By heating weak sulphuric acid with metallic copper, or roasted copper ores; by converting copper sulphides into sulphates by careful roasting, and extracting the salt by water; or by forming an artificial sulphide, and afterwards converting it into the sulphate by roasting.

Copper sulphate is a fine blue salt, crystallizing in triclinic prisms. On exposure to the air, these crystals effloresce and assume a whitish appearance.

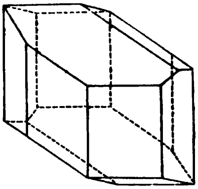


Fig. 124.
Copper Sulphate.

Copper sulphate is employed in large quantities in electro-metallurgy, in calico-printing, and in the preparation of the various copper pigments. It is also employed as a mild caustic for diseases of the eyelids.

When ammonia is added to a solution of cupric sulphate, a flocculent bluish-white precipitate is formed, which, in excess of the ammonia, dissolves and forms a deep blue liquid called *ammoniacal copper sulphate*, or $CuSO_4 + 4NH_3 + H_2O$.

303. Other Compounds of Coppor.—*Cupric nitrate*, or copper nitrate, $Cu(NO_3)_2$, is obtained by the action of nitric acid on metallic copper. This salt imparts a deep green color to flame.

Copper arsenite, $CuHAsO_3$, or Scheele's green, is obtained by precipitating copper sulphate by potassium arsenite.

Copper carbonates occur native in malachite and azurite.

304. Characteristics of Copper Salts.—Hydrogen and ammonium sulphides yield a black precipitate with copper salts, which dissolves in warm dilute nitric acid, and produces a blue solution that becomes dark blue on the addition of an excess of ammonium hydrate.

Potassium ferrocyanide gives a characteristic mahogany-brown precipitate.

The most characteristic test is the metallic deposit of copper that appears on a bright piece of iron when it is dipped in any solution containing copper.

The salts of copper are blue or green. They impart a green color to an otherwise colorless flame. They are poisonous.

SYLLABUS.

Magnesium, zinc, and cadmium are dyads. They volatilize at high temperatures, and burn with a bright flame when heated in the air. They decompose water at high temperatures.

Magnesium occurs naturally in magnesian limestone, or dolomite, as soapstone, talc, hornblende, and in a variety of other mineral substances. It is obtained in a metallic state by the action of metallic sodium on the chloride.

Metallic magnesium has a brilliant silver-white lustre, and is ductile and malleable. It is not oxidized at ordinary temperatures, but when heated in the air burns with a brilliant dazzling light, producing magnesium oxide.

Calcined magnesia is obtained by calcining the carbonate.

Magnesium hydrate is formed by precipitating any soluble magnesium salt by caustic potash.

Magnesium chloride is used as a dressing for cotton goods.

Magnesium carbonate occurs native as magnesite. It is obtained artificially, as the white magnesia of the druggist, by precipitating Epsom salt by sodium carbonate.

Magnesium sulphate, or Epsom salt, occurs in the waters of certain mineral springs. It is used in medicine; in the dyeing and preparation of cotton goods, and as a manure.

The salts of magnesium give no precipitate with either hydrogen sulphide or ammonium sulphide, but with sodium carbonate give a white, flocculent precipitate.

The principal ores of zinc are zinc blende, or the sulphide; calamine, or the hydrous silicate, and smithsonite, or the carbonate.

To extract the zinc, the ores are first roasted, and are then crushed and mixed with charcoal and heated, when the zinc is reduced and volatilized, and the vapor condensed in suitably arranged vessels or chambers.

Metallic zinc has a bluish-white color and a brilliant crystalline fracture. Between 212° F. and 300° F. it is quite ductile and malleable. Commercial zinc is readily dissolved by hydrochloric and sulphuric acids.

Metallic zinc is largely employed for galvanizing iron; in the manufacture of brass, and for producing sheet zinc.

Zinc oxide, or zinc white, used as a paint, is formed by burning the vapor of zinc in a current of air.

Zinc chloride is obtained by dissolving metallic zinc in hydrochloric acid. It is employed in surgery as a caustic; is used as a soldering solution; to prevent the decay of animal or vegetable substances, and for weighting cotton goods.

Zinc sulphate, or white vitriol, is obtained by roasting the sulphide. It has a bitter, astringent taste, and is used in dyeing and as an eye-wash.

The salts of zinc give a white precipitate with hydrogen sulphide and ammonium sulphide. They give a white precipitate with potassium ferrocyanide.

Cadmium is obtained from the yellowish-brown powder that condenses during the early parts of the distillation of the ores of zinc.

Metallic cadmium has a white lustre and a fibrous fracture. It is malleable and ductile, is harder than tin, and can take a high polish. It yields a dark yellow vapor at high temperatures.

Cadmium oxide is a yellowish-brown powder, formed when the metal is burned in the air. Cadmium sulphide occurs native as the mineral greenochite. It is thrown down as a yellow precipitate when hydrogen sulphide is passed through a solution of a cadmium salt.

Cadmium sulphate is obtained by dissolving cadmium in dilute sulphuric acid.

Mercury and copper are dyads. They do not decompose water at a red heat and are readily oxidized by cold nitric acid or by hot sulphuric acid. They are precipitated from their metallic solutions by iron or zinc.

The principal ore of mercury is the sulphide, or cinnabar. It sometimes occurs in a pure or native state.

Mercury is extracted from its ore by roasting in furnaces that permit the entrance of air, when it is volatilized and condensed in suitably contrived vessels.

Pure mercury is a mobile, silver-white fluid, that is not oxidized at ordinary temperatures. It freezes at —39.2° F. and boils at 662° F. It readily combines with chlorine and bromine, and forms amalgams with most of the metals.

Mercury is largely used in the construction of physical and chemical apparatus; in the extraction of gold and silver from their ores; in gilding and silvering; in the manufacture of vermilion, and in medicine. Its salts are very poisonous.

Mercurous oxide, or the gray oxide of mercury, is obtained by the action of caustic potash on calomel.

Mercuric oxide, or the red oxide of mercury, is prepared commercially by the action of heat on mercuric nitrate. It is also prepared by precipitating a mercuric salt by caustic soda.

Mercurous chloride, or calomel, may be obtained by the action of heat on a mixture of mercurous sulphate and common salt. It is used in medicine.

Mercuric chloride, or corrosive sublimate, is obtained by the action of heat on a mixture of mercuric sulphate and common salt. It is extremely poisonous. Its antidote is uncooked white of egg.

Mercuric sulphide, or cinnabar, may be obtained artificially by the direct union of mercury and sulphur. Vermilion is a rich scarlet pigment, produced by obtaining the sulphide in a fine state of division.

Mercuric iodide is a scarlet-red powder, precipitated when potassium iodide is added to a solution of corrosive sublimate. The red iodide may be changed to a yellow color by heat.

Mercuric sulphate is a white, crystalline powder, obtained by heating sulphuric acid and mercury. When thrown into an excess of cold water, it produces a lemon-colored precipitate, called turpeth mineral.

Mercuric nitrate is obtained by boiling mercury in nitric acid.

The salts of mercury yield a black precipitate with hydrogen sulphide or ammonium sulphide. The mercurous salts give a white precipitate with hydrochloric acid. They give a metallic precipitate of mercury on plates of copper, zinc, or iron, when dipped into solutions of their salts.

Copper occurs in the metallic state in nature. Its principal ores are the oxides, the sulphides, and the carbonates. It is extracted from its ores by several roastings, and reduction by charcoal.

Pure copper is the best known conductor of electricity. It is a tough, ductile, and malleable metal, possessing a peculiar red metallic lustre. It is largely employed for the production of wire and sheets.

Copper is unaffected by dry air at ordinary temperatures, but in the presence of moisture becomes coated with verdigris. It is readily dissolved by nitric acid, and by hot sulphuric acid.

Cuprous oxide, or red oxide of copper, occurs native as cuprite. It may be produced artificially by boiling copper acetate with glucose.

Cupric oxide, or black oxide of copper, occurs native as melaconite. It may be produced artificially by gently heating the nitrate.

Cuprous sulphide occurs native as copper glance. It may be produced artificially by burning copper in sulphur vapor.

Cupric sulphide occurs native as indigo copper. It may be produced artificially by the action of hydrogen sulphide on a copper salt.

Cuprous chloride occurs native as atacamite. It may be prepared artificially by the action of aqua regia on metallic copper. Dissolved in hydrochloric acid, it absorbs oxygen on exposure to the air, and forms a pigment called Brunswick green.

Cupric chloride is formed by dissolving cupric oxide in hydrochloric acid.

Cupric sulphate, copper sulphate, or blue vitriol, may be obtained by the action of hot sulphuric acid on metallic copper, or by roasting the native or artificial sulphide.

Copper sulphate occurs in fine blue crystals that contain five molecules of water. It is employed in electro-metallurgy, in calico-printing, and in the preparation of various pigments.

The copper salts may be recognized by the black precipitate formed by hydrogen sulphide or ammonium sulphide, which dissolves in nitric acid, producing a blue solution, that becomes of a dark-blue color on the addition of ammonium hydrate.

A bright plate of iron becomes coated with metallic copper when dipped into any solution containing a copper salt.

QUESTIONS FOR REVIEW.

Name some of the general properties possessed by magnesium, zinc, and cadmium.

Name the principal natural sources of magnesium. How is magnesium obtained in the metallic state? Name some of the properties of metallic magnesium.

Write the chemical formulæ for magnesium oxide and magnesium hydrate. How are these substances prepared? What is calcined magnesia?

How is magnesium chloride obtained? For what is it employed? Write the chemical formula for the crystalline salt.

What is the chemical composition of magnesite? How is the white magnesia of the apothecaries prepared?

What is the chemical composition of Epsom salts? For what purposes is it employed?

Describe some of the characteristics of the magnesium salts.

Name the principal ores of zinc. How are the ores treated for the extraction of the metal?

Describe the process known as "distillation per descendum." Describe the Silesian process.

Describe the properties of metallic zinc. For what purposes is metallic zinc employed in the arts?

How is zinc oxide prepared? What is its formula? For what is it employed in the arts? Why is zinc oxide preferable to carbonate of lead for a white paint? Write the chemical formula for zinc hydrate.

How is zinc chloride prepared? For what purposes is it employed?

What is the chemical composition of white vitriol? How is it prepared? For what is it employed?

Describe the principal characteristics of the zinc salts.

What is the principal source of cadmium? How is it obtained in a metallic state? Describe its properties.

Write the chemical formulæ of cadmium oxide and cadmium hydrate. How are they prepared?

Write the chemical formulæ for cadmium chloride and cadmium sulphide. How is each prepared? For what purpose is the latter employed?

How is cadmium sulphate prepared? For what is it used?

Describe the principal characteristics of the salts of cadmium.

State some of the general resemblances of mercury and copper.

What is the principal ore of mercury? How is the metal extracted from this ore? Describe the process adopted at Idria.

Describe the properties of metallic mercury. Name some of its uses. How is blue mass prepared?

Write the chemical formulæ for mercurous oxide and for mercuric oxide. How is each prepared? Describe the properties and uses of each.

What is the chemical composition of calomel? How does it differ from corrosive sublimate? Which is the more poisonous? Write the chemical reaction that occurs in the preparation of each. What is the antidote for corrosive sublimate?

What is the chemical composition of cinnabar? How is vermilion prepared?

How is mercuric iodide prepared? What curious property does it possess?

Distinguish between mercurous and mercuric sulphates. How is turpeth mineral obtained?

Write the chemical formulæ for mercurous and mercuric nitrates.

Describe some of the characteristics of the salts of mercury.

Name some of the principal ores of copper. Describe the method generally adopted for the extraction of copper from its ores. How are the waste sulphides, resulting from the sulphuric acid works, treated for the recovery of their copper?

Describe the properties of metallic copper. Name some of the purposes for which metallic copper is employed in the arts.

Distinguish between cuprous and cupric oxide. How is each prepared? Describe the properties and uses of each.

Distinguish between cuprous and cupric sulphide. How is each prepared?

Name the mineral forms of the cuprous and the cupric oxides, and the cuprous and the cupric sulphides.

What is the chemical composition of atacamite? How may it be prepared artificially? What is Brunswick green?

How is cupric chloride prepared? What is its composition?

How is cupric sulphate prepared? By what other names is it commonly known? Name some of the purposes for which cupric sulphate is employed. In what different ways may it be prepared?

What is the composition of ammoniacal copper sulphate? How is it prepared?

How is copper nitrate prepared? What is its chemical formula?

What is the composition of Scheele's green?

What is the chemical composition of malachite? of azurite?

Describe some of the characteristics of the salts of copper.

SECTION V.

THE TETRAD METALS.

GROUP I.

The Metals of the Platinum Group.

1. Platinum.	4. Rhodium.
2. Palladium.	5. Ruthenium.
3. Iridium.	6. Osmium.

GROUP II.

The Metals of the Tin Group.

1. Tin.	2. Titanium.

CHAPTER XV.

THE METALS OF THE PLATINUM GROUP.

305. Characteristics of the Group.—The metals of this group do not decompose water at any temperature. They have very little affinity for oxygen. Platinum does not combine directly with oxygen at any temperature. Palladium, iridium, and rhodium, only oxidize when heated in air or oxygen; but their oxides are decomposed at high temperatures, while ruthenium and osmium form volatile oxides, irreducible by heat alone. All the metals of this group manifest a strong attraction for chlorine and sulphur.

PLATINUM.

$Pt = 197.5$. Sp. Gr. $= 21.5$. Fuses at about 3632° F.

306. Occurrence and Extraction.—Platinum occurs in the form of a native alloy, consisting of about seventy-three to eighty-six per cent. of metallic platinum alloyed with small quantities of palladium, iridium, rhodium, ruthenium, osmium, and other metals, such as gold, iron, and copper. Its principal localities are in the Ural Mountains; in various parts of South America, and in the island of Borneo.

The following process is generally adopted to obtain the metal in a pure state. The ore is first separated from earthy matters by washing, and then acted on by dilute aqua regia, by means of which the gold and other comparatively soluble metals are removed. It is then heated in stronger aqua regia obtained by placing the ore in concentrated hydrochloric acid, to which small quantities of nitric acid are added from time to time. By this means the platinum is dissolved along with some of its associated metals. The liquid so obtained is neutralized by sodium carbonate, and then treated with mercury cyanide, by means of which palladium cyanide is precipitated. The remaining liquid is now treated with a solution of sal-ammoniac, which throws down a double chloride of ammonium and platinum, mixed with a small quantity of double chloride of ammonium and iridium. This precipitate is washed and gently heated to redness, by which ammonium chloride and chlorine are expelled, and the platinum reduced to a slightly coherent mass, called spongy platinum.

The spongy platinum is now thoroughly washed and powdered in a wooden mortar with water, and the metallic mud so produced is placed in a conical brass mould and submitted to powerful hydraulic pressure, by means of which it is converted into a compact mass. It is then heated in the intense heat of a powerful wind furnace and hammered, which operation, being several times repeated, produces the metal in a homogeneous and ductile condition.

Platinum has also been extracted by directly fusing its ore in a lime crucible by the flame of the compound blowpipe.

307. Properties and Uses of Metallic Platinum.—Metallic platinum is a metal having a tin-white color, and when polished, a high lustre. It is of about the same hardness as copper, and is very tenacious and ductile. It possesses, like iron, the property of welding at a white heat. It is infusible in masses, except at very high temperatures, but in the form of extremely fine wire can be melted in the flame of a Bunsen burner. When red hot it possesses, in a remarkable degree, the power of allowing hydrogen to pass through it.

Platinum is unaffected by oxygen at any temperature. None of the acids except aqua regia attack it. Heated to redness in air with caustic alkali, or with the alkaline earths, especially lime or baryta, it is rapidly corroded. It readily combines with phosphorus, and less easily with sulphur.

The principal use of metallic platinum is in the laboratory, where it is highly prized on account of its great infusibility and its power to resist acids. It is also used in chemical manufactories for stills for the concentration of sulphuric acid. It is also employed as a substitute for silver or amalgam in looking-glasses.

308. Platinum-Black.—When platinum chloride is dissolved in a strong solution of potassium hydrate, and alcohol added to the hot liquid, a brisk effervescence takes place, carbonic acid is evolved, and the platinum is obtained in a state of extreme division as a black powder. This is successively washed with alcohol, potash, and hydrochloric acid and water, and forms the well-known *platinum-black.* In this form platinum possesses a very great power of condensing gases. When a stream of hydrogen is allowed to play upon a piece of platinum-black, it condenses the gas so rapidly as to become red hot, and so ignite the gas. A self-lighting lamp is constructed on this principle.

Similar, but less energetic, properties are manifested by the platinum sponge, obtained by calcining the double chloride of platinum and ammonium, as already described.

309. Chlorides of Platinum.—There are two chlorides of platinum, viz., the dichloride, $PtCl_2$, and the tetrachloride, $PtCl_4$. The latter is the more important.

Platinum tetrachloride, $PtCl_4$, or platinic chloride, is obtained by dissolving platinum in aqua regia. A reddish-brown solution is obtained, which, on concentration, deposits red-brown deliquescent needles of the hydrated chloride. These are soluble in water and in alcohol.

When ammonium chloride in solution is added to a solution of platinum chloride, a double platinum and ammonium chloride is precipitated as a yellow crystalline powder. Its composition is $PtCl_4,2NH_4Cl$. A very great variety of these ammoniacal platinum compounds exist.

There are two oxides of platinum, viz., the monoxide, PtO, or platinous oxide, and the dioxide, PtO_2, or the platinic oxide. These give rise to a variety of unimportant platinous and platinic salts.

PALLADIUM.

Pd = 106.2. Sp. Gr. = 11.4. Discovered by Wollaston in 1803.

310. Occurrence and Properties.—Palladium, named by its discoverer, from Pallas, a then recently discovered asteroid, besides being associated with platinum ore, occurs in Brazil and in the Harz mountains in an alloy, containing a small quantity of gold.

It is separated from its associated metals by precipitating it from their solution in aqua regia by mercuric cyanide, which throws it down as an insoluble cyanide.

When pure, metallic palladium has a bright silver-white color, that, when heated to redness, changes to a violet or blue, regaining its lustre at still higher temperatures, and retaining it even when quickly cooled by plunging into cold water.

Metallic palladium is readily attacked by hot nitric and by concentrated, boiling sulphuric acid. It is not affected either by exposure to the air or to sulphurous gases, for which reason it is employed for the delicate graduated scales of mathematical instruments. As already mentioned, it possesses, in a remarkable degree, the power of occluding hydrogen.

It forms several oxides and a variety of palladious and palladic salts, that are mainly of theoretical interest.

IRIDIUM.

Ir = 192.7. Sp. Gr. = 22.38. Discovered by Tennant in 1804.

311. Occurrence and Properties.—In 1803, Tennant, after an investigation of the metallic residue remaining after the dissolving of platinum ores, announced his belief that they contained a new metal. Subsequently, in 1804, he discovered that they contained two new metals. To one of these he gave the name iridium, from Iris, the rainbow, from the varying color of its salts. To the other he gave the name osmium, from ὀσμή, a smell, on account of the pungent odor of its volatile oxide.

Iridium occurs native in a large proportion in the alloys *platiniridium* and *osmiridium.*

Metallic iridium has the lustre of polished steel. It is brittle when cold, but malleable at about a white heat. Next to osmium and ruthenium it is the most refractory of all the metals. In the form of iridium-black it has even greater power of condensing gases than platinum-black. It dissolves in aqua regia and oxidizes in the presence of the fused alkalies. Held in the flame of an alcohol lamp it becomes covered with a black carbide, IrC_4.

An artificial alloy of nine parts of platinum and one of iridium is exceeding hard and elastic, and was adopted by a Paris commission as the most suitable material for the construction of the standard weights and measures for the international metric system. Very great difficulties, however, were experienced in obtaining the alloy pure, and after five years of labor the trial was abandoned. Metallic iridium is sometimes used for pointing pens.

Iridium forms two oxides, Ir_2O_3 and IrO_2; a number of hydroxides, and a variety of iridious and iridic salts. The salts of iridium are in nearly all cases highly colored, and often change their color in a marked manner by heat or on exposure to the air.

RHODIUM.

Rh = 104.1. Sp. Gr. = 12.1. Discovered by Wollaston in 1804.

312. Occurrence and Properties.—This metal was discovered by Wollaston about the same time that he discovered palladium. He named it rhodium, from ῥόδον, a rose, in reference to the color of solutions of its salts. It occurs in nature alloyed with gold, in a mineral called *rhodium-gold.*

Metallic rhodium has nearly the same color and lustre as aluminium. On exposure to the air the melted metal becomes covered with blue oxide. When pure the metal is almost insoluble in acids. It is more easily attacked by chlorine than any of the other metals of this group. It forms three oxides, RhO, Rh_2O_3, and RhO_2, and a number of salts. These are colored either dark red or yellow.

RUTHENIUM.

Ru = 103.5. Sp. Gr. = 12.26. Discovered by Osann in 1828.

313. Occurrence and Properties.—This metal is associated with the platinum ores and alloys, and also occurs native as a sulphide. Its name is derived from Russia, where it was first discovered. Care is required in the preparation of the metal, as one of its volatile oxides is poisonous.

Ruthenium is a hard, brittle metal, that oxidizes slowly in the air. It is very slightly attacked by aqua regia. It forms no less than six different oxides. The tetroxide, RuO_4, is very volatile, emitting a golden-yellow vapor, which produces distressing coughing and irritation of the mucous membrane like nitrous fumes. A number of ruthenious and ruthenic salts exist. The ruthenious chloride, Ru_2Cl_6, imparts a reddish color to water, and deposits, on being heated, a very finely divided black oxychloride, that imparts a clearly marked, ink-like tint to 100,000 parts of water. This reaction is quite distinctive.

OSMIUM.

Os = 198.6. Sp. Gr. = 22.47. Discovered by Tennant in 1804.

314. Occurrence and Properties.—Osmium occurs associated with the platinum minerals. It is the heaviest substance known, and has never yet been fused.

Metallic osmium is of a bluish-white color and violet lustre. It is harder than glass, and is employed to some extent for forming the tips of gold pens. When heated up to the melting-point of iridium it evaporates, the vapor taking fire in air and forming the volatile tetroxide OsO_4.

Great danger attends this volatilization. The volatile oxide causes violent pain in the eyes, and often produces a permanent loss of sight from the subsequent reduction of a film of the metal. It forms a great variety of salts, readily detected by the volatile and pungent tetroxide, which is formed when they are heated.

CHAPTER XVI.

TIN AND TITANIUM.

315. Characteristics of the Group.—Both of the metals of this group form dioxides and volatile tetrachlorides, and in this respect, as well as in their powerful affinity for fluorine, closely resemble the non-metallic element silicon.

TIN.

Sn = 118. Sp. Gr. = 7.37. Melts at 442° F.

316. Occurrence and Metallurgy.—The principal ore of tin is the oxide, which occurs in greater or less purity in the mineral *tin-stone*, or *cassiterite*, which occurs in veins, or in small nodules or sand in the beds of adjoining streams; in the latter condition it is known as stream tin. Its principal localities are Cornwall; Saxony; the islands of Borneo and Banca; in New South Wales, and in various parts of North and South America. Its ores are generally associated with compounds of sulphur, arsenic, or other metals.

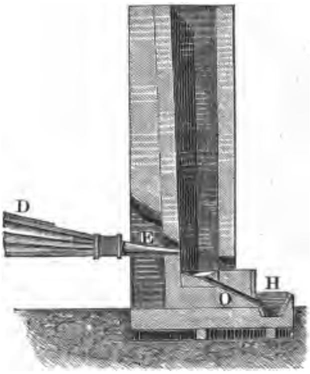


Fig. 125.—Extraction of Tin.

In order to extract the metal, the ore is first roasted, by means of which it is freed from most of its sulphur and arsenic. It is then washed in order to free it from any soluble salts that may have been produced, and to separate the lighter oxides. The purified ore is then mixed with charcoal and heated in a furnace, shaped as shown in Fig. 125. The air is supplied to this furnace by the bellows, D, through the pipe or tuyère, E. The carbon monoxide formed, reduces the tin, and the molten metal collects on the hearth, and is drawn from it through the opening, O, into a suitable receptacle, H. The molten metal in H is freed from dross by stirring with rods of green wood, and then run into moulds.

The tin thus produced contains traces of copper, iron, arsenic, lead, and antimony. It is freed from these by a process called *liquation*, which consists in gently heating the crude tin on the hearth of a reverberatory furnace, and running off the pure tin, which melts first.

317. Properties and Uses of Metallic Tin.—Pure tin is a white, lustrous metal, that is volatile at a white heat, and has a hardness intermediate between lead and gold. It has a fibrous, crystalline structure, and when bent produces a peculiar crackling noise, known technically as the "*cry of tin*," due to the friction of the crystalline particles. It is quite malleable and ductile.

Tin is unaltered by exposure to air or moisture, but is oxidized when exposed to the air in a molten state. It is dissolved rapidly in hot hydrochloric acid with a liberation of hydrogen, and in cold dilute nitric acid.

Tin is employed in large quantities for coating sheet-copper and sheet-iron. Commercial *tin plate* is simply sheet-iron previously cleansed from oxide, and dipped in a bath of molten tin, which combines with the surface layers of the iron, and forms an alloy, which, in turn, is covered with pure tin.

Copper vessels are tinned in order to prevent the formation of poisonous copper salts by acid foods cooked therein.

Tin forms, with lead and copper, a number of very valuable alloys, which have already been mentioned.

Phosphor bronze is a recently discovered alloy, possessing great tenacity, hardness, and elasticity. It is formed by ing together copper and tin phosphide, and occasionally a lead.

Tin combines with mercury and forms an amalgam much employed in the manufacture of looking-glasses.

Experiment 80.—*To make a looking-glass.* Pour some mercury on a piece of tin-foil, spread evenly over a piece of window-glass; spread the mercury over the foil until it completely covers it; allow it to stand for a few moments until it forms an amalgam with a portion of the foil; then slide a plate of thoroughly cleansed glass over the surface of the amalgam, so as to sweep all the oxide before it; and when the amalgam on the foil has been completely covered by the glass, carefully remove the lower plate, and the foil will adhere closely to the cleansed glass, converting it into a mirror.

318. Compounds of Tin and Oxygen.—There are two oxides of tin, viz., SnO and SnO_2.

Tin monoxide, SnO, or stannous oxide, may be obtained as a white precipitate by adding potassium carbonate in solution to a solution of tin dichloride.

Tin dioxide, SnO_2, or stannic oxide, occurs crystallized in nature as cassiterite. It may be obtained artificially in a finely-divided state by heating tin in air to nearly its boiling-point.

When a solution of calcium carbonate is carefully added to a solution of stannic chloride, a white hydrated oxide, having the formula H_2SnO_3, is formed. This hydrate possesses acid properties, and is known as *stannic acid.* It forms a class of salts known as the stannates. A metastannic acid also exists.

319. Compounds of Sulphur and Tin.—There are two sulphides of tin, viz., SnS and SnS_2. The latter is the more important.

Tin disulphide, SnS_2, is obtained by subliming a mixture of tin amalgam, sulphur, and sal-ammoniac. The reaction which takes place is quite complicated. The disulphide occurs in translucent, gold-colored, crystalline scales, known commercially as *mosaic gold.* It is extensively employed as a bronze powder.

320. Compounds of Chlorine and Tin.—Tin forms two compounds with chlorine, viz., $SnCl_2$ and $SnCl_4$.

Stannous chloride, $SnCl_2$, or tin dichloride, is obtained commercially by dissolving tin in hydrochloric acid. The solution, on evaporation, yields transparent crystals of the hydrated chloride, $SnCl_2+2H_2O$, known commercially as *tin salt.* It is used in the arts as a mordant in dyeing. It also possesses reducing properties. The hydrated chloride dissolves in a small quantity of water, but when added to an excess of water, throws down a white oxychloride.

Stannic chloride, $SnCl_4$, or tin tetrachloride, is obtained when tin-foil burns in chlorine gas. A liquid is thus formed, known as the *fuming liquor of Libavius*, from the white fumes it emits on exposure to the air, by the absorption of atmospheric moisture. When brought into contact with one-third its weight of water, it forms a hydrate known as *butter of tin.* Stannic chloride is employed by dyers as a mordant.

321. Characteristics of the Salts of Tin.—Hydrogen and ammonium sulphides give a brown precipitate with the stannous salts, and a yellow precipitate with the stannic salts. Both of these precipitates are soluble in excess of ammonium sulphide.

Chloride of gold gives the characteristic purple of Cassius with stannous solutions, but none in pure stannic solutions.

Metallic iron or zinc precipitates metallic tin from any of its solutions.

Any salt of tin placed on a carbonized match-stem, and held in the reducing cone of a flame, gives a malleable bead of tin, soluble in hot hydrochloric acid.

◆

TITANIUM.

Ti = 48. Discovered by Gregory in 1789.

322. Occurrence and Properties.—Titanium occurs naturally in a number of minerals, such as *rutile, brookite,* and *ana-*

tase. It was thoroughly investigated and named by Klaproth in 1795.

Metallic titanium cannot be prepared by any of the ordinary metallurgical processes, from the fact that the metal possesses the curious property of combining directly with nitrogen, to form titanium nitride.

When obtained pure it is a dark-gray amorphous powder, having a bright metallic lustre. When heated it burns brightly in the air, producing titanium dioxide and titanium nitride. When warm it is soluble in hydrochloric acid, and also in dilute nitric and sulphuric acids.

Titanium forms several oxides, the dioxide, TiO_2, which occurs in nature in *rutile, brookite,* and *anatase,* and the sesquioxide, Ti_2O_3. Titanic iron-ore has the composition $(FeTi)_2O_3$. Titanium forms a variety of salts.

◆

SYLLABUS.

Platinum does not combine directly with oxygen at any temperature. Palladium, iridium, and rhodium only oxidize when heated in air or oxygen, and their oxides decompose at a high temperature. Ruthenium and osmium form volatile oxides.

Platinum occurs in nature alloyed with palladium, iridium, rhodium, ruthenium, osmium, gold, and other metals.

Metallic platinum has a tin-white color, and takes, when polished, a high lustre. It is very malleable, ductile, and tenacious, and welds at a white heat. Its hardness is about that of copper.

Platinum is unaffected by oxygen at any temperature, and is not dissolved by any of the acids except aqua regia. Heated to redness in the air, in the presence of caustic lime or baryta, it is gradually corroded.

Metallic platinum is employed in the construction of crucibles, retorts, and stills for the laboratory.

Platinum-black is a name applied to metallic platinum in a state of minute division. It possesses to a marked degree the power of condensing gases.

There are two chlorides of platinum, viz., the dichloride, $PtCl_2$, and the tetrachloride, $PtCl_4$. The latter combines with ammonium chloride to form a great variety of double salts.

There are two oxides of platinum, viz., the monoxide, PtO, and the dioxide, PtO_2. These give rise to a variety of platinous and platinic salts.

Palladium, named from the asteroid Pallas, occurs in nature associated with the platinum ores.

Metallic palladium has a bright, silver-white color, that changes to violet or blue when heated in air to redness, but regains its lustre at higher temperatures. It is employed for the delicate graduated scales of mathematical instruments, on account of its being unaffected by sulphurous gases.

Iridium, named from Iris, the rainbow, on account of the varying color of its salts, is associated naturally with platinum ores.

Metallic iridium has the lustre of polished steel. It is very refractory. It dissolves in aqua regia, oxidizes in the presence of the fused alkalies, and combines readily with carbon.

Alloyed with nine times its weight of platinum, iridium forms a substance possessing remarkable hardness and elasticity.

The salts of iridium are highly colored, and change their color in a marked manner on being heated or exposed to the air.

Rhodium, from ῥόδον, a rose, from the rose color of solutions of its salts, occurs naturally alloyed with gold.

Metallic rhodium resembles aluminium in color and lustre. The melted metal, on exposure to the air, becomes coated with a blue oxide. Pure rhodium is almost insoluble in acids.

Ruthenium occurs in nature associated with platinum ores and its alloys. It is a hard, brittle metal. Its tetroxide is very volatile and poisonous.

Osmium, from ὀσμή, a smell, occurs associated with the platinum minerals. It is the heaviest of known substances. It forms a volatile tetroxide even more poisonous than the corresponding ruthenium oxide. Metallic osmium is very hard, and is sometimes used to tip gold pens.

Both tin and titanium form dioxides and volatile tetrachlorides. In these respects they resemble silicon.

The principal ore of tin is the dioxide, or cassiterite, or stream tin. It occurs in veins, or in alluvial sands, in Cornwall, Saxony, Borneo, Banca, and in New South Wales.

Tin is extracted from its ore by first roasting it to drive off the associated sulphur and arsenic. It is then washed, mixed with charcoal, and heated in a suitable furnace.

Crude metallic tin is freed from the traces of copper, iron, arsenic, lead, and antimony by liquation; that is, the crude metal is gradually heated on the hearth of a reverberatory furnace, when the pure tin, which fuses first, is run off from the mass.

Metallic tin has a white color and a high lustre. It is volatile at a white heat. It has a fibrous, crystalline structure, and when bent emits a peculiar crackling sound, called the "cry of tin."

Metallic tin is both ductile and malleable, and has a hardness intermediate between lead and gold. It is unaltered by exposure to air or moisture.

Tin plate is sheet-iron coated with tin, by dipping cleansed plates of iron into a bath of the molten metal.

Tin forms a number of valuable alloys with lead and copper. Phosphor bronze is an alloy of tin, copper, and phosphorus. It has great tenacity, hardness, and elasticity.

Tin forms two oxides, viz., the monoxide, SnO, and the dioxide, SnO_2.

Stannic acid is a hydroxide of tin. Its formula is H_2SnO_3. It forms a class of salts called stannates.

Mosaic gold, or tin disulphide, is much used as a bronze powder. It is prepared by subliming a mixture of tin amalgam, sulphur, and sal-ammoniac.

Stannous chloride, $SnCl_2$, is obtained by dissolving tin in hydrochloric acid. It is used in dyeing as a mordant.

Stannic chloride, $SnCl_4$, is obtained by burning tin-foil in chlorine. It is employed in dyeing as a mordant.

Hydrogen sulphide and ammonium sulphide give a brown precipitate with stannous salts, and a yellow precipitate with stannic salts, soluble in excess of the latter reagent.

Titanium occurs naturally in rutile, brookite, and anatase.

Metallic titanium cannot be prepared by any of the ordinary metallurgical processes, because it combines directly with the nitrogen of the air to form a nitride.

Metallic titanium is a dark-gray amorphous powder, that possesses a metallic lustre. It burns brightly when heated in the air.

QUESTIONS FOR REVIEW.

With what metals are the platinum ores associated naturally? Describe the process generally adopted for extracting platinum from its ores. Describe the means adopted for obtaining the metal in a ductile, malleable condition.

Describe the properties of metallic platinum. What chemical substances can dissolve it?

Name some of the purposes for which metallic platinum is employed. Why is it used so much in the chemical laboratory?

How is platinum-black prepared? Describe a property it possesses. How may a self-lighting lamp be constructed by the use of platinum-black?

Write the formulæ for platinum dichloride and platinum tetrachloride.

How is the latter substance prepared? What oxides of platinum are there?

Who discovered palladium? What is the origin of the name? In what form does palladium occur in nature? What properties does this metal possess? For what is it employed?

Who discovered iridium? What is the origin of the name? How does iridium occur in nature? Describe some of the properties of metallic iridium. What circumstance can you relate concerning its alloy with platinum?

Who discovered rhodium? What is the origin of its name? How does it occur in nature? Name some of the properties of metallic rhodium.

Who discovered ruthenium? How does it occur in nature? Describe some of its properties. What very characteristic reaction does ruthenium chloride possess?

Who discovered osmium? What is the origin of its name? Describe some of its properties. What danger attends its volatilization? For what purpose is metallic osmium employed?

In what respects do tin and titanium resemble silicon?

What is the principal ore of tin? Where is it found? Describe its metallurgy. Describe the process of liquation.

Describe the properties of metallic tin. Name some of its uses. How is tin plate prepared?

What is the composition of phosphor bronze? Name some of the alloys of tin.

What two oxides of tin are there? How is stannic acid prepared?

In what manner is mosaic gold prepared? For what is it employed?

Write the chemical formulæ for stannous and stannic chlorides. How are these substances prepared? For what are they employed?

What is the composition of the fuming liquor of Libavius? Of butter of tin?

Describe the principal characteristics of the tin salts. How may the stannous salts be distinguished from the stannic salts?

Name some of the principal natural sources of titanium. By whom was the metal discovered? By whom was it investigated and named?

Why cannot metallic titanium be prepared by any of the ordinary metallurgical processes? Describe some of the properties of metallic titanium.

Which is the principal oxide of titanium? What is the composition of rutile, brookite, and anatase? What is the composition of titanic iron ore?

SECTION VI.

THE HEXAD METALS.

GROUP I.

The Metals of the Iron Group.

1. Iron.
2. Manganese.
3. Cobalt.
4. Nickel.
5. Indium.
6. Gallium.

GROUP II.

The Metals of the Chromium Group.

1. Chromium.
2. Molybdenum.
3. Tungsten or Wolframium.
4. Uranium.

CHAPTER XVII.

THE METALS OF THE IRON GROUP.

323. Characteristics of the Group.—The metals of the iron group decompose water at high temperatures. Their monoxides are basic. The sulphates of these oxides form, with the sulphates of the alkaline metals, double salts or alums, that are isomorphous with the magnesium sulphates. The metals iron, nickel, and cobalt possess magnetic properties. Indium and gallium, rare metals, whose properties have not yet been thoroughly studied, appear to belong to this group.

Their exact quantivalence is uncertain. They apparently act as dyads, tetrads, and hexads.

IRON.

Fe = 56. Sp. Gr. malleable = 7.79, cast = 7.29. Melts at 2786° F.

324. The Ores and Metallurgy of Iron.—Iron, which is, perhaps, the most useful of the metals, is widely and abundantly distributed. It occasionally occurs in the pure or native state, in meteoric masses, but is almost always in combination.

Some of the most important of its ores are the following, viz.: *magnetic oxide*, Fe_3O_4; *red haemitite* or *specular iron ore*, Fe_2O_3; *brown haemitite* or *limonite*, $Fe_2O_3+Fe(OH)_6$; *spathic iron* or *siderite*, $FeCO_3$, and *argillaceous iron ore.*

These ores are all more or less mixed with earthy matters, and often contain pyrites, in which case they are first roasted in order to drive off the sulphur. The iron oxide is then reduced by carbon. There are two principal processes adopted for the reduction of the ores. The first, which is practised to but a limited extent, is suitable for very rich ores; the second, which is almost universally adopted, is suitable for nearly all workable ores.

325. The Catalan Process is used only for rich ores like the haemitites and spathic iron. The ore is placed in a heap alongside of a heap of charcoal placed on the hearth of a furnace, shaped as shown in Fig. 126. A blast of air, driven through the tuyère, B, ignites the charcoal and heats the ore. The carbon dioxide first formed is reduced by the incandescent charcoal to carbon monoxide, which reduces the oxide of iron to the metallic state. The silica and alumina in the ore combine with a small quantity

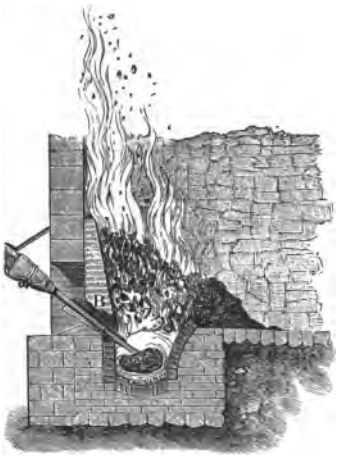


Fig. 126.—The Catalan Process.

of ferrous oxide produced during the reduction, and form a fusible slag, which is run off, while the metallic iron collects on the bottom of the hearth in a spongy mass, and is afterwards consolidated by hammering.

326. The Blast-Furnace Process.—This is a continuous process, adapted to almost every variety of ore, and is almost universally adopted.

The blast furnace is shown in Fig. 127. It consists, at the bottom, of a circular chamber called the *hearth*, and the *shaft* or *chimney*, which, as shown, is formed of two cones, the lower of which is called the *boshes*. These furnaces are often fifty feet high and ten feet in diameter at the top.

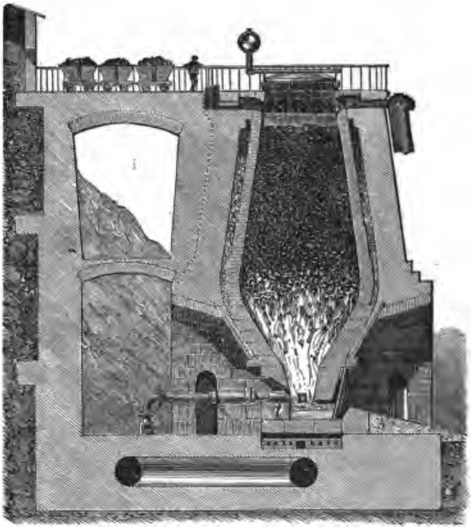


Fig. 127.—Blast Furnace for Iron.

Alternate layers of coal, iron-ore, and limestone are supplied, from time to time, at the top of the furnace. The combustion of the coal is effected by means of a blast of air driven into the furnace by the tuyères, one of which is shown at *t*, in the drawing.

In the lower parts of the furnace, carbon dioxide is formed. Towards the widest parts this is reduced by the incandescent coal to carbon monoxide, which still higher in the furnace reduces the iron-ore to a spongy metallic mass. As this mass slowly descends in the furnace, it unites with some of the carbon, and is freed from its silica and alumina by the union of these substances with a small quantity of iron and with the lime, to form a fusible slag. The melted iron sinks to the bottom of the furnace, and the lighter slag floats on its surface, and is drawn off from time to time through openings in the sides of the furnace. When the molten iron has collected in sufficient amount, it is run off and cast in bars known technically as *pig-iron.*

The air is generally heated before being driven into the furnace through the tuyère, as this has been found to be more economical of fuel, and to produce a larger yield of metal.

Pig-iron contains carbon. It occurs in numerous varieties, which, however, may be divided into two classes, viz., *white cast-iron* and *gray cast-iron.* The former has all its carbon combined with the iron; the latter has part of its carbon free and the rest combined.

Spiegel, or *specular pig-iron,* is a white cast-iron, containing the largest proportion of carbon (from 3.5 to 6 per cent.). It is employed in the manufacture of steel by the Bessemer process.

327. The Production of Wrought-Iron from Cast-Iron.— Wrought-iron contains very little carbon. It is obtained from cast-iron by two processes, viz., refining and puddling.

The pig-iron is first *refined* by fusing the iron in an oxidizing atmosphere, by means of which the carbon and the silicon are removed to a great extent. This produces a white, brittle, and highly crystalline iron, which is converted into tough wrought-iron by the puddling process, by which most of the carbon and silicon, together with the sulphur and phosphorus, are removed. The refined iron is placed on the hearth, *h,* of the puddling-furnace, Fig. 128, and heated, out of contact with fuel, and mixed or puddled with a mass of scales of oxide of iron. As the iron becomes purer, it grows less fusible, and, at last, is converted into a granular, sandy mass. The temperature is now raised, and the mass is worked into balls, or *blooms*, which are consolidated by powerful steam-hammers. The refining is sometimes effected in the puddling-furnace, when it is immediately afterwards puddled.

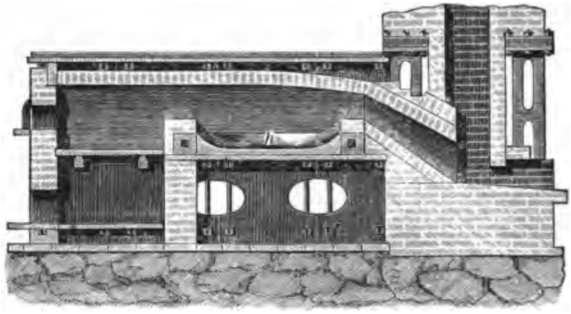


Fig. 128.—A Puddling Furnace.

328. Properties of Iron.—Wrought-iron, when hammered and rolled, has a fibrous texture if the quantity of carbon is very small; otherwise, it possesses a granular or crystalline structure. The presence of a small quantity of sulphur renders it *red-short*, that is, brittle while hot; a small quantity of phosphorus makes it *cold-short*, or brittle while cold. The presence of silicon and carbon increase the hardness of iron.

Pure iron has a silver-white color, and possesses a very high degree of tenacity. It is very ductile and malleable, and has the valuable property of welding at a white heat. It volatilizes in the heat of the voltaic arc.

Iron is not oxidized by dry air, but in the presence of moisture is soon covered with a layer of oxide or rust. It is quite soluble in dilute acids, with evolution of hydrogen.

Metallic iron, both wrought and cast, is employed for a vast variety of purposes, that are too well known to need recapitulation.

329. The Manufacture of Steel.—Steel is a variety of iron that has less carbon than cast-iron and more than wrought-iron. It is now produced almost entirely, by the Bessemer process, directly from cast-iron. In this process the molten metal has its carbon and silicon burned out from it by a blast of cold air driven through it. The molten cast-iron is placed in a vessel called the *converter*, shaped as in Fig. 129, and consisting of sheet-iron lined with some refractory material. The air bubbles through the molten metal, and, instead of cooling it, greatly increases its temperature by the heat evolved during the combustion of the carbon and the silicon. A bright flame escapes from the open mouth of the converter, and suddenly drops or disappears when the carbon has all been oxidized. The blast is then stopped, and a small quantity of *spiegel* is introduced, which converts the entire mass into cast steel, which is run into ingots; these may afterward be wrought under the hammer or roller.

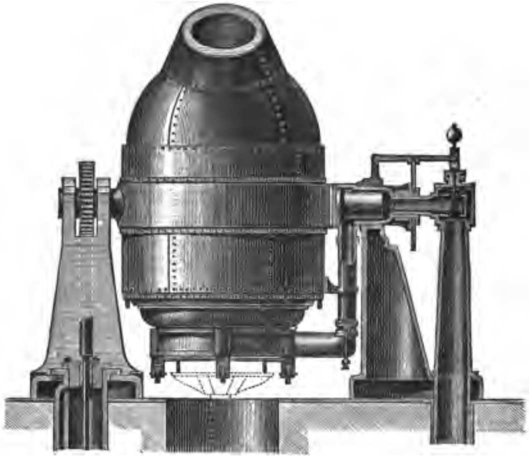


Fig. 129.—The Bessemer Process.

Steel is an extremely valuable metal. It is very tenacious, ductile, and malleable, and may be wrought under the hammer into any desired shape, and afterwards hardened by plunging, while red-hot, into a cold liquid like water or oil,—this process is called *tempering*, and renders the steel both hard and elastic, —or when hardened, if heated and allowed to slowly cool, it again becomes soft. By heating hardened steel to lower temperatures, and slowly cooling, some of the hardness remains. These processes are employed in the manufacture of edged tools.

330. Compounds of Iron and Oxygen.—There are three oxides of iron, viz., iron monoxide, FeO, and iron sesquioxide, Fe_2O_3, which unite and form the magnetic oxide of iron, Fe_3O_4.

Iron monoxide, FeO, or *ferrous oxide*, is formed as a black powder by passing a mixture of carbon monoxide and carbon dioxide over heated ferric oxide.

Iron sesquioxide, Fe_2O_3, or *ferric oxide*, occurs in nature both anhydrous and hydrated as the hematites. It may be prepared artificially by calcining ferric sulphate, or green vitriol, thus:

$$2FeSO_4 = Fe_2O_3 + SO_3 + SO_2.$$

In this form it occurs as an amorphous red powder, much employed as a paint, and as a polisher. *Rouge* is obtained in this way.

When ammonium hydrate is added to a solution of ferric chloride, it precipitates a flocculent, rust-colored, hydrated ferric oxide.

Rust is a ferric hydrate, and generally has the following composition, viz.:

$$2Fe_2O_3 + 3H_2O = Fe_2(OH)^6.$$

Magnetic oxide of iron, Fe_3O_4, or *Ferroso-ferric oxide*, occurs in nature as the mineral *magnetite*. It occurs as black scales, when iron is heated to redness in air.

331. Compounds of Iron and Sulphur.—Various sulphides occur in nature as *iron pyrites.* The principal of these, FeS_2, ordinary or cubical pyrites has a yellow, brass-like color; *marcasite,* or *white-iron pyrites,* FeS_2, and *magnetic iron pyrites* are other varieties.

Iron monosulphide, FeS, is obtained by burning iron in the vapor of sulphur, or by heating iron and sulphur together. It is a black, brittle substance, and is employed in the laboratory in the preparation of hydrogen sulphide.

332. Compounds of Iron and Chlorine.—*Ferrous chloride,* $FeCl_2$, may be obtained in transparent, bluish crystals by dissolving iron in hydrochloric acid, and concentrating the solution while protected from the air.

Ferric chloride, Fe_2Cl_6, is formed by passing chlorine over red-hot iron. The salt is soluble in water, producing a reddish yellow solution, and is employed in medicine.

333. Ferrous-Sulphate, $FeSO_4+7H_2O$, *Green Vitriol,* or *Copperas.* This important salt of iron is obtained commercially by the gradual oxidation of iron pyrites, by exposure to the air, or by gentle roasting. The mass is treated with water, and the sulphate separated by crystallization.

Ferrous-sulphate crystallizes in green crystals, that effloresce on exposure to the air, and at the same time absorb oxygen, forming a ferric sulphate.

Green vitriol is used largely in the arts in the manufacture of Prussian blue, inks, and iron mordants.

Ferric sulphate, $Fe_2(SO_4)_3$, may be formed by heating a solution of ferrous sulphate to which free sulphuric acid has been added, and slowly adding nitric acid. It forms a yellow-brown solution. Ammonium hydrate added to this salt produces a copious, flocculent, brown precipitate of hydrated ferric oxide, an antidote to arsenious acid.

334. Characteristics of the Salts of Iron.—Ferricyanide of Potassium instantly gives a dark-blue precipitate with ferrous salts, but with ferric salts gives no precipitate, only turning the liquid to a dark-brown.

Potassium ferrocyanide gives, with ferric salts, a dark-blue precipitate of Prussian blue; with ferrous salts, it gives a light-blue precipitate which darkens on exposure to air.

Potassium sulphocyanate gives, with ferric salts, a blood-red color.

The alkalies give, with ferrous salts, a whitish-green precipitate, quickly changing to dark-green, and finally to brown; with ferric salts, they immediately give a brown precipitate.

Solution of nut-galls give a bluish-black precipitate with a ferric salt. Ink is formed in this manner.

MANGANESE.

Mn = 55. Sp. Gr. = 8.0.

335. Occurrence and Properties.—Manganese occurs in nature in a number of minerals, the most important of which is *pyrolusite*, MnO_2. It may be obtained in a metallic state by exposing a mixture of the oxide, obtained by calcining the carbonate and charcoal, to a white heat in a crucible, lined with charcoal, and the remaining space filled with the same substance.

Metallic manganese is a brittle, hard, gray, or reddish-white substance. It is so readily attacked by oxygen that it must be kept under naphtha. It readily decomposes warm water.

336. Compounds of Manganese and Oxygen.—The following well-defined oxides exist, viz.:

Manganese monoxide, or manganous oxide, MnO.
Red manganese oxide, or manganoso-manganic oxide, Mn_3O_4.
Manganese sesquioxide, or manganic oxide, Mn_2O_3.
Manganese dioxide, or peroxide, MnO_2.
Manganese heptoxide, or permanganic anhydride, Mn_2O_7.

The first of these oxides has powerful basic properties; the last, when thrown into water, produces permanganic acid, $HMnO_4$. The remaining oxides are feebly basic.

Manganous oxide, MnO, is formed when manganous carbonate is ignited in a current of hydrogen. It is a grayish-green powder. When burned in the air it is converted into *red manganese oxide*, Mn_3O_4. The red oxide is also produced by calcining manganese dioxide.

Manganese dioxide, MnO_2, or *manganese peroxide*, or *black oxide of manganese*, occurs native in *pyrolusite*. It may be obtained artificially by gently igniting the nitrate. It is obtained in a hydrated condition by precipitating a manganese salt by a solution of an alkaline hypochlorite.

Manganese dioxide is employed in the arts to decolorize greenish glass. This it does by neutralizing the green tint by the rose-colored tint it would otherwise produce. Its name, *pyrolusite*, is derived from this circumstance. It is also used in the production of chlorine.

337. Manganic and Permanganic Acids.—*Manganic acid*, H_2MnO_4, does not exist in a free state. In combination it forms a well-defined class of salts called the *manganates*.

Potassium manganate, K_2MnO_4, is formed by fusing the dioxide with caustic potash. This substance is sometimes known as *chameleon mineral*. It is an unstable green salt, which, when thrown into a large quantity of water, colors it a deep green, which soon changes to a purple, and afterwards to a red color, hydrated dioxide of manganese being formed. The red liquid is potassium permanganate. The following shows what occurs, viz.:

$$3K_2MnO_4 + 3H_2O = K_2Mn_2O_8 + MnO_2H_2O + 4KOH$$

Potassium Manganate + Water = Potassium Permanganate + Hydrated Manganese Dioxide + Potassium Hydrate.

Potassium permanganate, $K_2Mn_2O_8$, may be obtained in nearly black crystals that possess a green metallic lustre. This salt has powerful oxidizing properties, and is extensively employed in the laboratory in volumetric analysis. It is also used largely as a disinfectant, for which purpose it is extensively manufactured in a partially pure state.

Experiment 81.—Pour some sulphurous acid water into a solution of potassium permanganate, and the color at once disappears; sulphuric acid is formed, through the oxidation of the sulphurous acid and the reduction of the permanganate.

338. Manganous Sulphate and Carbonate.—*Manganous sulphate*, $MnSO_4+7H_2O$, may be obtained in the form of oblique rhombic, rose-colored crystals, by the action of sulphuric acid on manganese carbonate. The salt also occurs in crystals containing less water than the above.

Manganese carbonate, $MnCO_3$, occurs native. It may be obtained in a hydrated form by precipitating a solution of the chloride by sodium carbonate.

Manganic sulphate, $Mn_2(SO_4)_3$, is obtained by dissolving the red oxide, Mn_3O_4, in sulphuric acid. It combines with potassium sulphate, K_2SO_4, to form a *manganese alum*, $K_2SO_4+Mn_2(SO_4)_3+24H_2O$.

339. Characteristics of the Salts of Manganese.—Ammonium sulphide gives a characteristic flesh-colored precipitate, with soluble salts of manganese.

Potassium and sodium hydrates give a white precipitate of hydroxide, which rapidly turns brown on exposure to the air.

A salt of manganese fused with a bead of borax in the outer flame of a blowpipe, colors the bead an amethyst blue. This bead held in the inner flame becomes colorless.

* * *

COBALT.

Co = 59. Sp. Gr. = 8.6. Discovered by Brandt in 1735.

340. Occurrence and Properties.—Cobalt occurs in nature, in combination with arsenic, as *tin-white cobalt*, $CoAs_2$; *cobalt glance*, $(CoFe)(AsS)_2$; *speiss cobalt*, $(CoNiFe)As_2$; and in various other forms. Cobalt is nearly always one of the constituents of meteoric iron.

The cobalt ores are generally treated for the production of *smalt* or *azure blue*, a potash glass, colored intensely blue by oxide of cobalt. For this purpose the ores are carefully roasted, so as to drive off the arsenic and sulphur, and the cobalt only is oxidized, the remaining metals being almost unaltered. The roasted mass is then fused with silicious sand and potash, and the resulting blue glass ground into a fine powder with water.

Metallic cobalt may be produced by igniting the chloride in an atmosphere of dry hydrogen. This metal has the appearance of bright iron. It is much harder than iron, has great tenacity, and is malleable. It is unaffected by air at ordinary temperatures, but oxidizes when heated. It is readily dissolved by dilute hydrochloric, nitric, and sulphuric acids.

341. Compounds of Cobalt and Oxygen.—Cobalt combines with oxygen to form two oxides.

Cobalt monoxide, CoO, or *cobaltous oxide*, is obtained as a light-brown or greenish-gray powder, by calcining the carbonate out of contact with air. It may be obtained as cobaltous hydrate, $Co(OH)_2$, by precipitating any cobaltous salt by potassium hydrate out of contact with air.

Cobalt sesquioxide, Co_2O_3, is obtained by igniting the hydrate. It is a dark-brown powder. These two oxides combine to form Co_3O_4, a compound corresponding to the magnetic oxide of iron.

342. Cobalt Chloride, $CoCl_2$, is obtained, as a sublimate, in the form of blue crystalline scales, by heating finely divided metallic cobalt in chlorine gas. It may also be obtained as an aqueous solution by the action of hydrochloric acid. The color of the solution is of a currant red, but changes to blue, from the formation of anhydrous chloride, if sulphuric acid is added and the solution concentrated.

Experiment 82.—Write on paper with the dilute rose-colored chloride of cobalt. The characters on drying will be invisible. Now hold the writing before the fire, and when the chemically combined water is driven off the writing appears of a blue color. On being again exposed to the air, moisture is absorbed, and the writing disappears. In this way a sympathetic ink is obtained.

343. Other Compounds of Cobalt.—*Cobalt sulphate,* $CoSO_4+7H_2O$, corresponds to ferrous sulphate. It is obtained as red crystals by dissolving the carbonate in weak sulphuric acid.

Cobalt nitrate, $Co(NO_3)_2+6H_2O$, is obtained by the action of nitric acid on the carbonate.

A great variety of ammoniacal compounds of cobalt exist.

344. Characteristics of the Salts of Cobalt.—The solutions of the cobaltous salts are rose-colored when dilute, and blue when concentrated, the latter especially in the presence of an acid.

Ammonium sulphide gives a black precipitate, insoluble in dilute hydrochloric acid.

A blue precipitate is formed by caustic potash, which turns to an impure blue on excess of the reagent being added.

A cobalt salt, reduced on a carbonized match-stem, gives metallic particles, that are attracted by a magnet, and dissolve in hydrochloric acid to form a rose-colored liquid.

* * *

NICKEL.

$Ni = 59$. Sp. Gr. = 8.66. Discovered by Cronstedt in 1751.

345. Occurrence and Properties.—The ores of nickel are most always associated with cobalt. Some of the most important are *kupfer-nickel,* NiAS; *nickel glance,* $Ni(AsS)_2$, and *linnaeite* $(CoNiFe)_3S_4$. It is always found in meteoric iron.

Metallic nickel may be obtained in small quantities by reducing the oxide. The extraction from its ores is a very tedious process.

Metallic nickel is a hard, grayish-white metal, capable of being highly polished. It is very ductile, malleable, and tenacious, and can be welded like iron. Like cobalt and iron, nickel is magnetic. It is unaffected by air at ordinary temperatures, and is for this reason, as well as for its fine lustre and polish, extensively employed for the electro-plating of the commoner metals.

Metallic nickel is dissolved by hydrochloric, and by dilute sulphuric or nitric acid. It forms valuable alloys with copper and zinc, such as German silver. It is also extensively employed in alloys for coin.

346. Compounds of Nickel and Oxygen.—There are two oxides of nickel.

Nickel monoxide, NiO, or *nickel oxide*, may be obtained as pale-green crystals by strongly igniting nickel borate with lime. It may be obtained as the hydrate, $Ni(OH)_2$, in the form of a precipitate of an apple-green color, by precipitating any solution of nickel by caustic potash. This oxide dissolves in ammonium hydrate, and produces a blue solution.

Nickel sesquioxide, Ni_2O_3, or *nickel peroxide*, is obtained as a black powder by gently igniting the carbonate in the air.

347. Nickel Chloride, $NiCl_2$, may be obtained as a golden-yellow sublimate by burning finely-divided nickel in dry chlorine. The hydrated chloride is produced by the action of hydrochloric acid on the carbonate. The solution is green, and deposits green crystals, $NiCl_2+9H_2O$. When mixed with the chloride of cobalt it produces a green sympathetic ink.

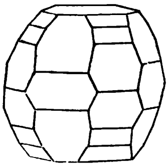


Fig. 130.
Nickel Sulphate.

348. Nickel Sulphate, $NiSO_4+7H_2O$.—This important salt of nickel, often called *nickel vitriol*, is prepared by dissolving the oxide or the carbonate in sulphuric acid. It separates from the solution in fine emerald-green crystals. It is extensively employed, in the form of *ammonium nickel sulphate* $(NH_4)_2SO_4+NiSO_4+6H_2O$, in electro-plating with nickel.

349. Characteristics of the Salts of Nickel.—The anhydrous nickel salts are of a yellow color; the hydrated salts are of a deep green.

Caustic potash and potassium carbonate yield apple-green precipitates with solutions of nickel salts.

The green hydrate, precipitated by ammonia, dissolves in excess of the reagent to form a blue liquid.

Potassium ferrocyanide gives, with solutions of nickel salts, a greenish-white precipitate.

INDIUM.

In = 113.4. Sp. Gr. = 7.42. Discovered by Reich and Richter in 1863.

350. Occurrence and Properties.—This metal was discovered in the zinc-blendes of Freiberg by means of a number of brilliant blue and violet spectroscopic lines. It may be obtained in a metallic state from the Freiberg metallic zinc by treating it with rather less hydrochloric acid than is sufficient to dissolve it; after standing for a number of days, the indium is precipitated on the undissolved zinc. The indium is extracted from this precipitate by a complicated process.

Pure indium is a soft, ductile metal, of a silver-white color. It is unaffected by air or moisture, but heated on charcoal by a blowpipe it colors the flame blue. It is dissolved by nitric, sulphuric, or hydrochloric acid.

Indium forms an oxide, In_2O_3, of a pale-yellow color, readily soluble in acids, and forming a number of salts. It forms a chloride, In_2Cl_6, when burned in chlorine.

The indium salts, moistened with hydrochloric acid, tinge a non-luminous flame a dark blue.

GALLIUM.

Ga = 69.9. Sp. Gr. = 5.9. Discovered by Lecoq de Boisbaudran in 1875.

351. Occurrence and Properties.—This metal was discovered by means of the spectroscope in a zinc-blende obtained from the Pyrenees. Its spectrum gives two characteristic violet lines.

Metallic gallium has a bluish-white color, and is sufficiently soft to be cut with a knife. It has the remarkably low melting-point of 96° F., the molten metal retaining its liquidity for days even at temperatures considerably below its point of fusion. The molten metal, poured on glass, coats it with a mirror-like deposit. It forms an oxide, Ga_2O_3, a chloride, Ga_2Cl_6, and a variety of other salts. Though it possesses very singular properties, yet it would appear to be allied to the iron group.

SYLLABUS.

The metals of the iron group include iron, manganese, nickel, and cobalt. Indium and gallium are also closely related to this group.

The metals of the iron group decompose water at a high temperature. Their monoxides are basic, and their sulphates form alums with the alkaline sulphates.

Some of the most important of the ores of iron are magnetic oxide, the red and brown hæmatites, spathic iron, and argillaceous iron ore.

To extract the iron, the ores are first roasted to drive off the sulphur, and are then reduced by charcoal.

In the Catalan process, the ore is heated by a blast of air driven through a mass of incandescent charcoal placed alongside a mass of heated ore. The spongy mass of metallic iron so obtained is then consolidated by hammering.

The blast-furnace process is a continuous one. Alternate layers of coal, iron ore, and limestone are placed in a high furnace, supplied with streams of hot air driven through openings called tuyères. The iron is reduced by the carbon monoxide. The limestone combines with the silica and alumina of the ore, and with part of the iron, and forms a fusible slag, which floats on the surface of the molten metal collected in the bottom of the furnace. The metal is run into moulds, and constitutes the cast-iron of commerce. Cast-iron always contains carbon.

There are a variety of cast-irons, but they may all be arranged under two classes, viz., a white cast-iron, which has all its carbon combined with the iron; and a gray cast-iron, which has part of its carbon uncombined. Spiegel, or specular pig-iron, employed in the Bessemer steel process, contains the greatest percentage of carbon.

To convert cast-iron into wrought-iron, the cast-iron is deprived of nearly all its carbon by two distinct processes, viz., refining and puddling. The iron is refined by melting it while exposed to an oxidizing atmosphere, by which most of the carbon and silicon are removed. The refined iron is puddled by being heated on the hearth of a puddling-furnace, where it is mixed or puddled into a mass of scales of oxide of iron. This removes nearly all the remaining carbon and silicon, together with the sulphur and phosphorus. The blooms so produced are consolidated by forging.

The presence of small quantities of phosphorus in iron makes it cold-short, or brittle when cold. The presence of sulphur makes it red-short, or brittle while hot.

Metallic iron has a silver-white color. It is very ductile, malleable, and tenacious, and can be welded at a white heat.

Steel is a variety of cast-iron, possessing more combined carbon than wrought-iron, but less than cast-iron. It is now prepared almost entirely by the Bessemer process.

In the Bessemer steel process, the cast-iron is melted and run into a vessel called the converter, in which the carbon and silicon are burned out by a stream of air forced through it. A quantity of spiegel, a variety of cast-iron containing a large percentage of carbon, is then added to the mass, and converts it into cast-steel.

Steel is an exceedingly tenacious, ductile, and malleable metal. It possesses the valuable property of becoming very hard and elastic by being suddenly cooled while red hot. Hardened steel may be annealed or softened by being allowed to slowly cool when highly heated.

There are two oxides of iron, viz., the monoxide and the sesquioxide. These combine to form the magnetic oxide.

The sulphides of iron occur in nature as different varieties of pyrites, which are mainly the bisulphide. Iron monosulphide is formed by heating iron and sulphur together.

Ferrous chloride is obtained by dissolving iron in hydrochloric acid; ferric chloride, by passing chlorine over red-hot iron.

Ferrous sulphate, or green vitriol, is obtained commercially by the gradual oxidation of iron pyrites. It is a pale-green salt, employed in the manufacture of Prussian blue, inks, and iron mordants.

Ferricyanide of potassium gives at once a dark-blue precipitate with ferrous salts, but merely changes the color of solutions of ferric salts to a dark-brown.

Ferrocyanide of potassium gives a dark precipitate of Prussian blue with ferric salts, and a light-blue precipitate with ferrous salts.

The alkalies give, with ferrous salts, a whitish precipitate, which rapidly changes to dark-green, and finally to brown, but with ferric salts give an immediate brown.

Ink is obtained by the action of an infusion of nut-galls on a ferric salt.

The principal ore of manganese is pyrolusite, so called because of its property of rendering a greenish glass colorless when fused with it.

Metallic manganese is a brittle, hard, gray or reddish-white substance, that readily oxidizes on exposure to the air, forming various oxides.

Manganous oxide, or the monoxide, is powerfully basic. When burned in the air it is converted into the red oxide. Manganese dioxide occurs in nature as pyrolusite.

Manganate of potash, or chameleon mineral, is obtained by fusing the dioxide with caustic potash. Thrown into water it produces a green solution, that rapidly changes to a purple, and subsequently to a red color, from the formation of potassium permanganate.

Potassium permanganate possesses powerful oxidizing and disinfecting properties, and is manufactured in large quantities.

Manganous sulphate is obtained by the action of sulphuric acid on the carbonate. Manganic sulphate is obtained by dissolving the red oxide in sulphuric acid. It combines with potassium sulphate to form a manganese alum.

Ammonium sulphide gives a characteristic flesh-colored precipitate with soluble manganese salts.

Potassium and sodium hydrate give a white precipitate, with manganese salts, which rapidly turns brown on exposure to the air.

Cobalt occurs in the mineral kingdom associated with sulphur, arsenic, and other substances. Its ores are generally treated for the manufacture of smalt, an intensely blue potash glass.

Metallic cobalt resembles highly-polished iron. It is very hard and tenacious, and is unchanged in air at ordinary temperatures.

Cobalt forms two oxides, the monoxide and the sesquioxide.

Cobalt chloride is obtained by heating finely-divided metallic cobalt in chlorine gas. Its solution is pale-rose color when dilute, and blue when concentrated. It is used as a sympathetic ink.

Cobalt sulphate is a red crystalline salt, obtained by dissolving the carbonate in weak sulphuric acid.

Caustic potash gives, with cobalt salts, a blue precipitate, that becomes of a dirty-blue color on exposure to the air.

A cobalt salt, reduced on a carbonized match stem, yields metallic particles that are attracted by a magnet, and dissolve in hydrochloric acid to form a pale-red liquid.

The ores of nickel are generally associated with sulphur, arsenic, cobalt, and other metals. The metal may be obtained in small quantities by reducing the oxide.

Metallic nickel is of a grayish-white color. It is very hard, and can take a high polish. Since it is not affected by air or moisture at ordinary temperatures, it is largely employed for electro-plating easily oxidizable metals.

Nickel combines with oxygen to form a monoxide and a sesquioxide.

Nickel chloride is obtained as a greenish solution by the action of hydrochloric acid on the carbonate. Mixed with the chloride of cobalt it forms a green sympathetic ink.

Nickel sulphate, or nickel vitriol, is obtained by dissolving the oxide or the carbonate in sulphuric acid. It is used as ammonium nickel sulphate in electro-plating.

Caustic potash and potassium carbonate yield apple-green precipitates with nickel salts.

Ammonium hydrate gives a green precipitate, which is soluble in excess, forming a blue liquid.

Indium is a rare metal that occurs associated with the zinc blendes of Freiberg. It is soft and ductile, and has a silver-white color. Its spectrum gives a number of characteristic blue and violet lines. Indium salts, moistened with hydrochloric acid, tinge a colorless flame a dark-blue.

Gallium is a rare metal that is associated with certain zinc blendes obtained from the Pyrenees.

Metallic gallium has a bluish-white color, and a remarkably low melting point.

QUESTIONS FOR REVIEW.

Name the metals of the iron group. What two additional metals may be included in this group?

Describe some of the resemblances of the metals of the iron group.

Name the principal ores of iron. How are these ores treated for the extraction of the iron?

Describe the Catalan process for the reduction of iron. Describe the blast-furnace process. Which of these is the more commonly used? Describe the construction of a blast-furnace for iron.

Distinguish between the cold- and the hot-blast processes for the reduction of iron. Explain the manner in which the iron is reduced in the blast-furnace. What becomes of the silica and alumina contained in the ores?

Name and describe two kinds of cast-iron.

How is wrought-iron obtained from cast-iron? Describe the refining process. Describe the puddling process.

Distinguish between cold-short and red-short iron.

Describe some of the properties of wrought-iron. Describe some of the properties of pure iron.

What is the composition of steel? Describe the Bessemer steel process. Why does not the air-blast chill the molten cast-iron? What is the use of the spiegel in this process?

Describe some of the properties of steel. How may steel be hardened? How may it be annealed? How may its temper be drawn?

Write the chemical formulæ for the various oxides of iron. How may each of these oxides be obtained? What is the composition of iron pyrites? How is iron monosulphide obtained? For what is it used?

Write the chemical formulæ for ferrous and ferric chlorides. How may each of these be prepared?

What is the composition of crystallized ferrous sulphate? How is this salt prepared commercially? For what purpose is it employed?

How is ferric sulphate produced? For what is it used?

Describe some of the characteristics of the salts of iron.

What is the principal ore of manganese? For what purposes is it employed?

Write the chemical formulæ for the oxides of manganese. Which of these oxides is basic? Which has acid properties?

Describe the process for making potassium manganate or chameleon mineral. What is the origin of the latter name?

How is potassium permanganate obtained? For what different purposes is it employed?

How is manganous sulphate produced?

How is manganic sulphate produced?

Describe some of the characteristics of the salts of manganese.

Name some of the principal ores of cobalt. What is smalt? How is it prepared from the cobalt minerals?

Describe the properties of metallic cobalt. Write the formulæ for its oxides and hydrates. How is each of these obtained?

How is cobalt chloride produced? What curious property does it possess? Write the chemical formulæ for cobalt sulphate and nitrate.

Describe some of the characteristics of the salts of cobalt.

Name some of the principal ores of nickel. How may metallic nickel be obtained on a small scale?

Describe the properties of metallic nickel. For what purposes is nickel employed in the arts?

Write the chemical formulæ for the oxide and the hydrate of nickel. How is each of these obtained?

How is nickel chloride obtained? Write the formula for the crystallized salt.

How is nickel sulphate obtained? For what purpose is it principally employed?

Describe some of the principal characteristics of the salts of nickel.

What is the principal natural source of indium? Describe the properties of this metal. How was it discovered?

What is the principal natural source of gallium? What very curious properties does this metal possess? How was the metal discovered?

CHAPTER XVIII.

THE METALS OF THE CHROMIUM GROUP.

352. Characteristics of the Group.—All the metals of the chromium group form trioxides, and are therefore sexivalent; they are, however, sometimes bivalent and quadrivalent. Their trioxides form acids that produce characteristic groups of salts.

Chromium was formerly ranked with iron, on account of the resemblance of its lower oxide to the corresponding oxide of iron.

CHROMIUM.

Cr = 52.5. Sp. Gr. = 5.9. Discovered by Vauquelin in 1797.

353. Occurrence and Properties—The name chromium was given to this element from χρῶμα, color, because all its salts are colored. Its principal ores are *crocoisite*, or lead chromate, $PbCrO_4$, and *chrome iron ore*, or chromite, $FeOCr_2O_3$. It also occurs in traces in a variety of minerals, to which it imparts a deep color.

It may be obtained in a metallic state by intensely igniting a mixture of chromic oxide and sugar in a lime crucible. Thus prepared it is obtained as a light-green powder that contains, as may be seen by the aid of a microscope, crystals of a tin-white color. This metal is as hard as corundum, and is less fusible than platinum. It oxidizes slowly when heated in air, and dissolves in hydrochloric acid and in warm sulphuric acid.

When alloyed with steel in rather less than one per cent., it renders this substance exceedingly hard.

354. Compounds of Chromium and Oxygen.—Chromium forms with oxygen the following oxides, viz.:

Chromous oxide, or Chromium monoxide $= CrO$.
Chromic oxide, or Chromium sesquioxide $= Cr_2O_3$.
Chromium trioxide, or Chromic anhydride $= CrO_3$.

The first two are basic, the last acid-forming. These oxides combine among themselves, and form other oxides.

Chromium monoxide, CrO, only occurs as a hydrate, $Cr(OH)_2$, which is formed as a brownish-yellow precipitate, when caustic potash is added to a solution of chromous chloride.

Chromic oxide, Cr_2O_3, or *Chromium sesquioxide*, occurs naturally in an impure state in *chrome ochre.* It may be prepared artificially by the action of heat on mercurous chromate, thus:

$$2Hg_2CrO_4 + \text{Heat} = 4Hg + O_5 + Cr_2O_3$$

Mercurous Chromate + Heat = Mercury + Oxygen + Chromic oxide.

Thus prepared it has a fine green color, and is used as a permanent green paint, known as *chrome green,* and is also employed to impart a rich green tint to glass, enamel, and porcelain.

Chromic hydrate is obtained as a flaky, green precipitate, by adding ammonium hydrate to a solution of chromic chloride.

Chromium trioxide, CrO_3, or *chromium anhydride,* is readily prepared by gradually adding to a cold saturated solution of potassium bichromate, one and a half times its volume of concentrated sulphuric acid. The liquid assumes a deep-red color, and deposits scarlet, needle-like deliquescent crystals of the trioxide.

Chromium trioxide is a powerful oxidizing substance, and is readily changed into the green sesquioxide by the ordinary reducing agents; many organic compounds also reduce it; thus, if the dry trioxide is mixed with a small quantity of powdered camphor, and strong alcohol be dropped on it, the reduction takes place with incandescence, and a vegetable-like growth of the sesquioxide is formed.

Heated with hydrochloric acid the following reaction occurs, viz.:

$$\begin{array}{ccccccccc} 2CrO_3 & + & 12HCl & = & Cr_2Cl_6 & + & 6H_2O & + & 3Cl_2 \\ \text{Chromium Trioxide} & + & \text{Hydrochloric Acid} & = & \text{Chromic Chloride} & + & \text{Water} & + & \text{Chlorine.} \end{array}$$

355. The Chromates.—Chromic acid forms a number of salts known as chromates; the following are among the more important, viz.:

Potassium neutral chromate, K_2CrO_4, or *yellow chromate of potash*, is readily obtained in fine yellow rhombic pyramids, by evaporating the solution formed by adding potash to a solution of potassium dichromate. It is freely soluble in water, to which it imparts an intense yellow tint, clearly recognizable in 400,000 parts of water.

Potassium dichromate, $K_2Cr_2O_7$, or *bichromate of potash*, is the most important of the chromium compounds, since it is generally from this salt that the others are indirectly obtained. The bichromate of potash is prepared by roasting chrome-iron ore with potassium nitrate.

Potassium dichromate crystallizes in magnificent garnet-red triclinic prisms. This salt is largely employed in dyeing; in calico-printing, and for the preparation of the chromium pigments.

Experiment 83.—When a sheet of paper, soaked in a solution of potassium dichromate, is exposed to the light it becomes of a darker color, owing to the reduction of the chromic oxide by the organic matter of the paper. If a sheet of such paper, dried in the dark, be laid under a photographic negative, or under some natural object, such as a fern leaf, and exposed to sunlight, a photographic print will be obtained.

Lead chromate, $PbCrO_4$, is obtained as the pigment *chrome yellow*, by precipitating a soluble lead salt by potassium dichromate.

Basic lead chromate, or *chrome red*, Pb_2CrO_5, is obtained by the action of cold caustic soda on chrome yellow.

356. Compounds of Chromium and Chlorine.—*Chromous chloride*, $CrCl_2$, is a powerful reducing agent, obtained by dissolving metallic chromium in dilute hydrochloric acid. Its solution in water has a blue color.

Chromic chloride, Cr_2Cl_6, is of a violet color, and is obtained by heating a mixture of chromic oxide and carbon in an atmosphere of dry chlorine. This salt is very sparingly soluble in water, unless it contains a trace of chromous chloride, when it readily dissolves and forms a green liquid, which, on evaporation, yields green crystals of a hydrate, $Cr_2Cl_6 + 12H_2O$.

Chromium oxychloride, CrO_2Cl_2, or *chlorochromic anhydride*, is obtained as a mobile liquid of a magnificent blood-red color, by distilling a fused mixture of potassium bichromate and common salt with concentrated sulphuric acid. It forms *chlorochromic acid*, $HCrO_3Cl$, which produces a class of salts called the chlorochromates.

357. Characteristics of the Salts of Chromium.—The salts of chromium are all highly colored. Caustic alkalies precipitate a grayish-green hydrate when added to a soluble chromium compound.

The presence of chromic acid or its salts is recognized by the crimson precipitate it forms with salts of silver, the bright yellow precipitate formed with salts of lead, and the pale yellow precipitate formed with salts of barium.

MOLYBDENUM.

Mo = 95.8. Sp. Gr. = 8.6. Discovered by Bergman in 1781.

358. Occurrence and Properties.—This metal occurs in the mineral kingdom principally as *molybdenite*, MoS_2; as the molydenate of lead, or *wulfenite*, $PbMoO_4$, and as *molybdic ochre*, MoO_3.

Metallic molybdenum is obtained by heating the chloride to redness in an atmosphere of hydrogen. It has a silver-white color, and a hardness somewhat exceeding that of silver, It is a very refractory metal, and decomposes water at a red heat. It is soluble in nitric acid and in strong, hot sulphuric acid.

Molybdenum forms numerous compounds with oxygen and chlorine. The following oxides are known, viz., MoO, Mo_2O_3, MoO_2, and MoO_3. The latter is an acid-forming oxide, producing a class of salts known as the *molybdates*. The other oxides are basic.

The following chlorides exist, viz., $MoCl_2$, Mo_2Cl_6, $MoCl_4$, and $MoCl_5$. The pentachloride, $MoCl_5$, is remarkable as indicating that molybdenum is capable at times of acting as a pentad.

TUNGSTEN (OR WOLFRAMIUM).

W = 183.5. Sp. Gr. = 19.12. Discovered by José and d'Elhujar in 1783.

359. Occurrence and Properties.—Tungsten, or Wolframium, is a very rare metal, that occurs in the mineral kingdom, chiefly in the minerals *tungsten*, or *heavy-stone*, $CaWO_4$, and in *lead tungstate*, $PbWO_4$.

Metallic tungsten is obtained by heating tungsten trioxide and carbon in a crucible out of contact with air. The pure metal has a bright gray metallic lustre. It is unaffected at ordinary temperatures by air or moisture, but burns in air when heated to a red heat, producing the trioxide. When added in very small quantity to steel it is said to greatly improve its hardness and tenacity.

Tungsten forms two oxides, viz., the dioxide, WO_2, a basic substance, and the trioxide, WO_3, which forms tungstic acid, H_2WO_4, and metatungstic acid, $H_2WO_3+7H_2O$, from each of which a large class of salts is obtained.

Tungsten forms a number of chlorides, viz., WCl_2, WCl_4, WCl_6, and an anomalous, WCl_5.

URANIUM.

U = 240. Sp. Gr. = 18.3. Discovered by Klaproth in 1789.

360. Occurrence and Properties.—Uranium is a rare metal, that occurs principally in the mineral *pitch-blende*, which contains U_3O_8, associated with a number of other substances. It took its name from the planet Uranus, discovered at about the same time as the element.

Metallic uranium is obtained by the action of metallic potassium on uranous chloride. The pure metal has the same color as nickel, and, like that metal, is hard and malleable. It is not affected by air at ordinary temperatures, but when sufficiently heated, burns in the air, producing the green oxide. It readily combines with chlorine and sulphur.

Uranium combines with oxygen to form two oxides, UO_2, and UO_3, which combine to form intermediate oxides. Uranium dioxide, UO_2, dissolves in strong acids, producing a class of green salts. Uranium dioxide, UO_2, is regarded as a compound radical, and is called *uranyl.* According to this view, UO_3 is an oxide of uranyl, or $(UO_2)O$. This radical forms a great variety of salts known as the *uranyl compounds*, such, for example, as $UO_2SO_4+3H_2O$, or uranyl sulphate, and $UO_2(NO_3)_2+6H_2O$, or uranyl nitrate.

This same radical combines with basic metallic oxides, and forms a class of salts called the *uranates*, such, for example, as $Na_2U_2O_7$, or sodium uranate, much employed for imparting a yellowish-green color to glass.

Uranium combines with chlorine and forms UCl_4, U_2Cl_6, and the anomalous, UCl_5.

* * *

SYLLABUS.

The metals of the chromium group include chromium, molybdenum, tungsten or wolframium, and uranium. They are all sexivalent.

Chromium derives its name from χρῶμα, color, from the bright colors of all its compounds.

The principal ores of chromium are crocoisite, or lead chromate, and chromite, or chrome iron ore.

Chromium may be obtained in the metallic state by intensely igniting a mixture of chromic oxide and sugar in a lime crucible.

Metallic chromium has a tin-white color. It is as hard as corundum, and is less fusible than platinum. When added in very small quantities to steel it greatly increases the hardness of the latter.

Chromium combines with oxygen to form a number of oxides.

Chromium monoxide may be obtained as a hydrate by adding caustic potash to a solution of chromous chloride.

Chromic oxide may be obtained by the action of heat on mercurous chromate.

Chromium trioxide, or chromium anhydride, may be obtained in the form of scarlet-red needle-shaped crystals by gradually adding to a cold saturated solution of potassium dichromate, one and a half times its bulk of strong sulphuric acid.

Chromium trioxide is a powerful oxidizing substance, and is converted into the green sesquioxide by any reducing agent.

Potassium neutral chromate is obtained in the form of magnificent yellow crystals, by evaporating the solution obtained by adding potash to a solution of dichromate of potash.

Potassium dichromate, or bichromate of potassium, is obtained by roasting chrome iron ore with potassium nitrate. It crystallizes in splendid garnet-red crystals. It is much used in calico-printing, in dyeing, and in the preparation of the chromium paints.

Chlorine combines with chromium and forms two chlorides, viz., the chromous and the chromic.

Chromium oxychloride, or chlorochromic anhydride, is obtained by distilling a fused mixture of potassium dichromate and common salt with concentrated sulphuric acid. It is a mobile liquid of a splendid blood-red color.

The salts of chromium are all highly colored. They yield a grayish-green precipitate with caustic alkali, a crimson precipitate with any salt of silver, and a bright yellow precipitate with any soluble lead salt.

The principal ores of molybdenum are molybdenite, or the disulphide; wulfenite, or the molybdenate of lead, and molybdic ochre, or the trioxide. Metallic molybdenum is obtained by heating the chloride to redness in an atmosphere of hydrogen.

Metallic molybdenum is a very refractory metal of a silver-white color, and a hardness somewhat exceeding that of silver. It is soluble in nitric and in strong sulphuric acids.

Molybdenum forms a remarkable number of oxides and chlorides. It forms both basic and acid oxides.

Tungsten, or Wolframium, is a rare metal that is found in tungsten or heavy-stone, $CaWO_4$, and in lead tungstate, $PbWO_4$.

Metallic tungsten is obtained by heating the trioxide with carbon in a covered crucible. It has a bright gray metallic lustre, and is unaffected by air or moisture at ordinary temperatures.

Tungsten forms two oxides, viz., the dioxide, WO_2, a basic substance, and the trioxide, WO_3, which forms tungstic acid, H_2WO_4, and metatungstic acid, $H_2WO_3+7H_2O$.

Uranium is a rare metal that occurs associated with the mineral pitchblende.

Metallic uranium is obtained by the action of metallic potassium on uranous chloride. It has a color similar to that of nickel. It is hard, malleable, and is not affected by air or moisture at ordinary temperatures.

There are two oxides of uranium, UO_2 and UO_3.

Uranium dioxide is regarded as a compound radical called uranyl, which forms both uranyl compounds, such as $UO_2SO_4+3H_2O$, or sulphate of uranyl, and uranates, as $N_2U_2O_7$, or sodium uranate.

Sodium uranate is employed in the arts for imparting a green color to glass.

QUESTIONS FOR REVIEW.

Name the metals of the chromium group. Describe some of the characteristics of this group. Which of the oxides of these metals form bases? Which form acids?

What is the origin of the word chromium? What are the principal ores of chromium?

How is chromium obtained in a metallic state? Describe its principal properties.

Write the chemical formulæ for the oxides of chromium. How is chromium monoxide produced? Chromic oxide? What is chrome green? How is it formed?

How may chromium anhydride be prepared? What is its chemical composition? Describe its properties. What effect has chlorine on chromium anhydride?

How is potassium neutral chromate prepared? Describe its properties.

How is potassium dichromate prepared? What are its properties? For what purpose is it employed in the arts?

How may photographic prints be obtained by the use of bichromate of potassium? To what is this change of color due?

What is the composition of chrome yellow? What is the composition of chrome red? Of chrome green?

Write the chemical formula for chromous chloride. How is it obtained? What is the chemical formula for chromic chloride? How is it obtained?

What is the composition of chlorochromic acid? How may chlorochromic acid be produced?

How may the presence of the salts of chromium be detected?

From what mineral substances may molybdenum be obtained? How may molybdenum be obtained in the metallic state? What are the properties of metallic molybdenum?

What four oxides of molybdenum are there? Which of these are basic? Which produces acids?

Write the chemical formulæ for the chlorides of molybdenum. Which of these is anomalous in its composition? In what respect is it anomalous?

Name some of the minerals that contain molybdenum or wolframium. How may this metal be obtained in the metallic state? What are its properties?

Name the two oxides of tungsten. What classes of compounds do these oxides produce?

Name the principal source of the metal uranium. How may this metal be obtained in the metallic state? Describe some of its properties.

Which are the principal oxides of uranium? What is the composition of the compound radical uranyl? What two classes of compounds does this radical form? Give an example of each of these classes.

What color is imparted to glass by uranium?

PART III.—ORGANIC CHEMISTRY.

SECTION I.

PRELIMINARY PRINCIPLES.

CHAPTER I.

INTRODUCTORY.

361. The Scope of Organic Chemistry.—The almost innumerable compounds that are formed by animals and plants, and substances derived from them, consist of carbon combined with some of the other elementary substances. These substances are generally known as organic substances.

It was formerly believed that organic substances could not be formed artificially; that their constituent elements could only be combined to form these substances, under the peculiar influence of the vital force; or, in other words, that organic substances could not be formed artificially in the laboratory.

The recent advances in chemistry have shown that the synthesis of organic substances is quite possible, and that they are formed under precisely the same laws that govern the combinations of the inorganic substances already mentioned.

By an organic substance, therefore, as we now understand the term, is meant a substance similar to those formed under the influence of animal or plant life, either naturally or artificially. Since all these substances contain carbon, we may define an organic substance to be one containing carbon.

Organic chemistry treats of the composition and properties of all carbon compounds. Strictly speaking, this would include carbon monoxide and dioxide, but it is more convenient to consider these compounds under inorganic chemistry.

362. The Constituent Elements of Organic Bodies.—The elements that most frequently occur in organic substances are carbon, hydrogen, oxygen, and nitrogen. These elements are sometimes called the *immediate principles.* To them sulphur may be added as an occasional immediate principle.

By artificial methods, however, as will be hereafter more fully described, all the elements may become integral parts of organic substances, and, in this way, the number of possible carbon compounds is almost innumerable.

363. Ultimate or Elementary Analysis of Organic Compounds.—There are various methods by which the proportions of the constituent elements of an organic compound may be ascertained; or, in other words, its ultimate analysis effected.

If the organic substance contains carbon, hydrogen, and oxygen only, the quantity of carbon and hydrogen contained in a given weight is carefully ascertained, which, subtracted from the total weight, gives the amount of oxygen.

The method usually adopted for ascertaining the proportion of carbon and hydrogen is that proposed by Liebig. In this process the carbon and hydrogen are oxidized by means of cupric oxide, the carbon dioxide and water so produced being absorbed in tubes or bulbs containing caustic potash and calcium chloride. These tubes or bulbs are carefully weighed before and after the operation, the quantity of carbon and oxygen being calculated from their increase in weight.

The process is conducted as follows: a small quantity of the substance to be analyzed, which we will suppose to be a solid, is carefully weighed and mixed in a mortar with some recently ignited black oxide of copper, CuO, which has been cooled out of contact with air. A combustion-tube of difficultly fusible glass, closed only at *d*, and shaped as shown in Fig. 131, is first filled to *c*, with the oxide of copper; the mixture from the mortar is then introduced into the tube, which it fills say as far as *b*; the mortar is then rinsed with some more copper oxide, with which the tube is filled to *a* or farther.

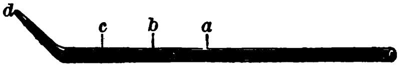


Fig. 131.—Combustion-Tube.

The tube so prepared is held horizontally and gently tapped, so as to form a canal for the passage of the evolved gas, and exposed to a high temperature in a combustion-furnace, A, Fig. 132, its open end, B, being connected with the tubes as shown; the tube, *h*, contains fragments of calcium chloride, the U-tube, *i*, contains pumice-stone saturated with sulphuric acid; *h* and *i* absorb the water produced, and are called the water-tubes; *j*, the carbonic acid tube, shown on an enlarged scale in Fig. 133, contains a concentrated solution of caustic potash, and is arranged so that the gases bubble slowly through it, and so insures the complete absorption of the carbonic acid. The tube, *k*, contains pumice-stone saturated with sulphuric acid.

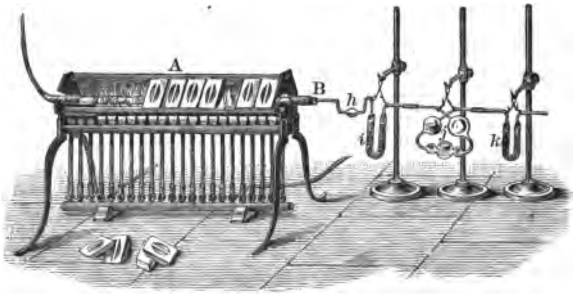


Fig. 132.—Liebig's Process for Organic Analysis.

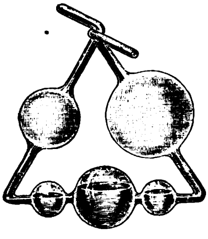


Fig. 133. Liebig's Potash Bulb.

The furnace may be heated either by coal or gas; in that shown in the figure, gas is employed, being supplied to a number of Bunsen burners. The flame is first applied to near the open end of the combustion-tube, and afterwards throughout its entire length. When gas is no longer given off, the sealed end of the tube is broken off, and dry air passed through in order to wash out any residual vapor or carbon dioxide. The water and carbonic acid tubes are then carefully weighed, and the quantity of hydrogen and carbon present determined.

A convenient form for the tube containing the calcium chloride is shown in detail in Fig. 134.

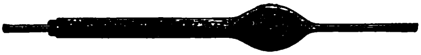


Fig. 134.—Chloride of Calcium Tube.

364. Determination of the Nitrogen.—Several methods are employed for determining the quantity of nitrogen.

The nitrogenous substance may be mixed with cupric oxide and burned in a combustion-tube, as already explained; water, carbonic acid gas, and nitrogen being given off. The water is absorbed, and the carbonic acid and nitrogen received in a graduated jar, J, Fig. 135, in a mercury trough; on the surface of the mercury in the jar is a solution of potassium hydrate, which absorbs the carbonic acid gas, when the nitrogen remains, and may be estimated from its volume.

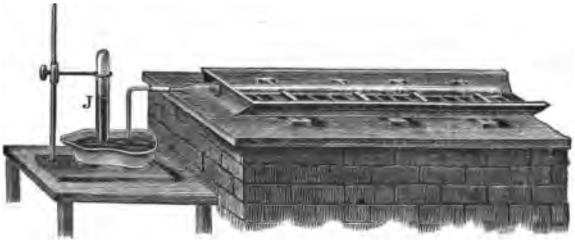


Fig. 135.—Estimation of Nitrogen.

Or the nitrogen may be converted into ammonia by heating the nitrogenous substance in the presence of an alkali. The nitrogenous substance is mixed with from five to six times its weight of lime and caustic soda, and placed in a combustion-tube, connected with a hydrochloric acid bulb, *a*, Fig. 136, which absorbs all the ammonia gas evolved. At the close of the operation the contents of the bulb are washed out, and treated with solution of platinic chloride, which converts the absorbed ammonia into a double chloride of platinum and ammonium. From the weight of this chloride the quantity of nitrogen may be readily calculated.

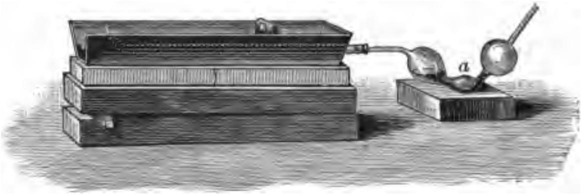


Fig. 136.—Hydrochloric Acid Bulb.

365. Estimation of Sulphur.—A substance containing sulphur may be treated with cupric oxide, as already described, in which case sulphurous oxide is evolved, and may be absorbed by a bulb containing lead dioxide.

Another method is to oxidize the sulphur by nitric acid, and thus convert it into sulphuric acid, estimating the quantity of the latter by weighing the insoluble barium sulphate it produces when treated with a soluble barium salt.

366. Determination of the Molecular Formulæ.—The percentage proportions of the constituent elements thus determined are now to be reduced to their *empirical formulæ;* that is, to the formulæ representing the relative proportions of the constituent atoms.

As an example we will take the case of an analysis of 100 parts of cane-sugar by the preceding methods. There were found:

Carbon	42.10 parts.
Hydrogen	6.43 "
Oxygen	51.46 "

The relative proportions of the respective carbon, hydrogen, and oxygen atoms must, of course, be as these numbers divided by their respective atomic weights, viz.:

$$\frac{42.10}{12} = 3.51 \quad \frac{6.43}{1} = 6.43 \text{ and } \frac{51.46}{16} = 3.22.$$

Or say, 350 atoms of carbon, 643 of hydrogen, and 322 of oxygen.

Now it must be remembered that the results of ultimate organic analysis are only approximately correct; judgment must, therefore, be exercised in determining the proportions of the atoms. The hydrogen and oxygen atoms are evidently present in the proportion to form water; that is, in about the proportion of 2 to 1. Again, the carbon and hydrogen are nearly as 12 : 22; that is, $\frac{350}{29} = 12$ nearly, and $\frac{643}{39} = 22$ nearly; therefore we conclude that the empirical formula $C_{12}H_{22}O_{11}$ correctly represents the composition of sugar.

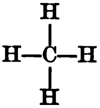
If the molecular weight be known the problem is much simpler: thus, the molecular weight of sugar = 342, then

If 100 parts sugar contain 42.10 parts of carbon, 342 parts contain 144 parts.
" " " " " 6.43 " hydrogen, " " " " 22 "
" " " " " 51.46 " oxygen, " " " " 176 "

$$\text{Or, } C = \frac{144}{12} = 12,\ H = \frac{22}{1} = 22,\ \frac{176}{16}\ O = 11.$$

367. Determination of the Molecular Weight.—The simplest method of determining the molecular weight is to determine the vapor density as compared with hydrogen, when, as we have already seen, the molecular weight can be at once determined by multiplying the density by 2, since the molecules of all compound substances, in the state of vapor, occupy a volume exactly equal to that of the molecule of hydrogen, which contains two atoms. If the organic substance is not volatile, it is combined in a definite form with another body, the atomic composition of which is known. The molecular weight may then be readily calculated.

368. Chemical Structure of Organic Bodies.—The basis or groundwork of the organic molecule is the tetrad carbon atom; thus,

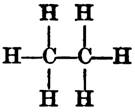


$$\begin{array}{c} H \\ | \\ H-C-H \\ | \\ H \end{array}$$

Methane.

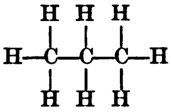
Any elementary atom may unite with each of the four bonds of the carbon atom, as in CH_4, or methane; and if its valency is higher than one, it may thus afford several points for the attachment of other atoms.

One of the peculiarities of organic compounds is the linking of carbon atom to carbon atom; thus,



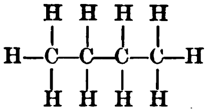
$$\begin{array}{ccccccc} & & \mathrm{H} & & \mathrm{H} & & \\ & & | & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{H} \\ & & | & & | & & \\ & & \mathrm{H} & & \mathrm{H} & & \end{array}$$

Ethane.



$$\begin{array}{ccccccccc} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \\ & & | & & | & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{H} \\ & & | & & | & & | & & \\ & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \end{array}$$

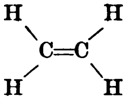
Propane.



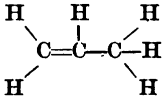
$$\begin{array}{ccccccccccc} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \\ & & | & & | & & | & & | & & \\ \mathrm{H} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{C} & - & \mathrm{H} \\ & & | & & | & & | & & | & & \\ & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \mathrm{H} & & \end{array}$$

Butane.

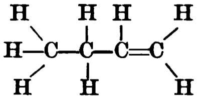
The carbon atoms, however, may unite thus:



Ethylene.



Propylene.

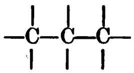


Butylene.

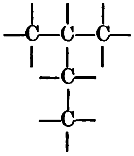
Or thus, $H{-}C{\equiv}C{-}H$, or Acetylene.

When it is borne in mind that the number of carbon atoms in the molecule may be greatly increased, being in the case of *stearine* no less than fifty-seven, and that these may be variously grouped, and that each bond may be satisfied by multivalent atoms, the innumerable variety of chemical compounds of the carbon group will be understood.

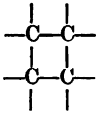
A few of the forms of the carbon nucleus are here shown:



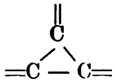
Simple chain.



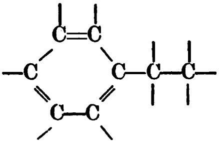
Side chain.



Closed chain or carbon ring.



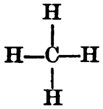
Closed chain or carbon ring.



Carbon ring with side chain.

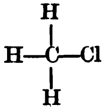
It is evident that the valency of the carbon nucleus depends on the manner in which the carbon atoms are grouped.

369. Formation of Organic Bodies. Theory of Substitution or Replacement.—Any carbon nucleus may combine with as many elementary atoms as it has free bonds; or if all its bonds are satisfied, it may have any of its constituent atoms replaced or substituted by some other atom of the same valency; thus,



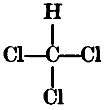
$$\begin{array}{c} H \\ | \\ H-C-H \\ | \\ H \end{array}$$

Marsh Gas or Methane.



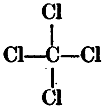
$$\begin{array}{c} H \\ | \\ H-C-Cl \\ | \\ H \end{array}$$

Monochlor-methane.



$$\begin{array}{c} H \\ | \\ Cl-C-Cl \\ | \\ Cl \end{array}$$

Trichlormethane (Chloroform).

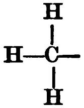


$$\begin{array}{c} Cl \\ | \\ Cl-C-Cl \\ | \\ Cl \end{array}$$

Carbon Tetrachloride.

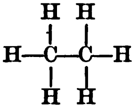
When the carbon nucleus has its carbon atoms joined by more than one bond it may form new compounds by simple addition of new atoms. In this case one of the bonds of a carbon atom is freed, and is satisfied by the added atom.

Or, one or several of the bonds may be satisfied by an *organic radical;* that is, by an *unsaturated* carbon nucleus; thus the unsaturated nucleus



$$\begin{array}{c} H \\ | \\ H-C- \\ | \\ H \end{array}$$

or the radical Methyl, may combine with itself, thus,

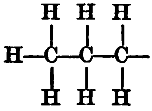


$$\begin{array}{ccccc} & H & & H & \\ & | & & | & \\ H- & C & - & C & -H \\ & | & & | & \\ & H & & H & \end{array}$$

and form Dimethyl, Ethane, or Ethyl hydride.

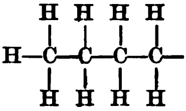
Or regarding C_2H_5 as an unsaturated nucleus, or radical *ethyl,* then its saturation with H forms ethyl hydride.

So also the compound radicals,



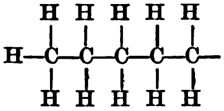
$$\begin{array}{c} H\ H\ H \\ |\ \ |\ \ | \\ H-C-C-C- \\ |\ \ |\ \ | \\ H\ H\ H \end{array}$$

Propyl.



$$\begin{array}{c} H\ H\ H\ H \\ |\ \ |\ \ |\ \ | \\ H-C-C-C-C- \\ |\ \ |\ \ |\ \ | \\ H\ H\ H\ H \end{array}$$

Butyl.

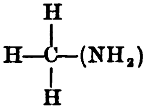


$$\begin{array}{c} H\ H\ H\ H\ H \\ |\ \ |\ \ |\ \ |\ \ | \\ H-C-C-C-C-C- \\ |\ \ |\ \ |\ \ |\ \ | \\ H\ H\ H\ H\ H \end{array}$$

Amyl.

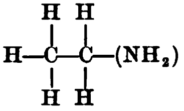
when combined with hydrogen, form propyl hydride or propane, butyl hydride or butane, and amyl hydride or pentane, respectively.

Again, the radical $—N{=}H_2$, or *amine*, may unite with the unsaturated bond of the radicals methyl, ethyl, propyl, butyl, or amyl, forming methylamine, ethylamine, etc.; thus,



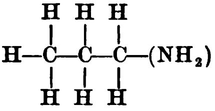
$$\begin{array}{c} H \\ | \\ H—C—(NH_2) \\ | \\ H \end{array}$$

Methylamine.



$$\begin{array}{c} H\;H \\ |\;\;| \\ H—C—C—(NH_2) \\ |\;\;| \\ H\;H \end{array}$$

Ethylamine.



$$\begin{array}{c} H\;H\;H \\ |\;\;|\;\;| \\ H—C—C—C—(NH_2) \\ |\;\;|\;\;| \\ H\;H\;H \end{array}$$

Propylamine.

Or the radicals methyl, ethyl, propyl, butyl, amyl, etc., may unite with one another; thus,

$CH_3—C_2H_5$	$CH_3—C_3H_7$	$CH_3—C_4H_9$, etc., etc.
Methyl-ethyl.	Methyl-propyl.	Methyl-butyl.

Or their free bonds may be satisfied by one of the haloids; thus,

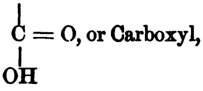
$CH_3—I$	$C_2H_5—I$	$C_3H_7—I$	$C_4H_9—I$, etc.
Methyl Iodide.	Ethyl Iodide.	Propyl Iodide.	Butyl Iodide.

370. Alcohols.—When the compound radical —OH combines with methyl, ethyl, propyl, butyl, amyl, etc., the resulting compounds or hydrates, are called *alcohols;* thus,

$CH_3—OH$ = methyl hydrate, or methylic alcohol.
$C_2H_5—OH$ = ethyl hydrate, or ethyllic "
$C_3H_7—OH$ = propyl hydrate, or propylic "
$C_4H_9—OH$ = butyl hydrate, or butylic "
$C_5H_{11}—OH$ = amyl hydrate, or amylic "

371. Organic Acids.—When the compound radicals methyl, ethyl, propyl, butyl, amyl, etc., combine with the compound radical

$—CO.OH$ or



$$\begin{array}{c} | \\ C = O \\ | \\ OH \end{array}$$

, or Carboxyl,

a class of organic acids results; thus:

Acetic acid $= C_2H_4O_2 = CH_3—CO.OH$.
Propionic " $= C_3H_6O_2 = C_2H_5—CO.OH$.
Butyric " $= C_4H_8O_2 = C_3H_7—CO.OH$.
Valeric " $= C_5H_{10}O_2 = C_4H_9—CO.OH$.
Caproic " $= C_6H_{12}O_2 = C_5H_{11}—CO.OH$.

The hydrogen in the group —CO.OH is strongly basic, and may be replaced by any equivalent quantity of metal, thus forming salts; thus: $Cu(C_2H_3O_2)_2+H_2O$ = acetate of copper.

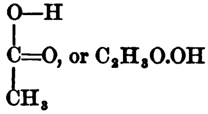
372. Empirical and Rational Formulæ.—An *empirical formula* represents merely the nature and number of the constituent atoms; thus: $C_2H_4O_2$ = acetic acid.

A *rational formula* represents the theoretical mode of formation of the compound, and consequently the mode of its decomposition. The symbols, therefore, are not written once only, as in empirical formulæ, but are repeated as may be necessary to show the nature of the combination, as also the varying strength of the union; thus: CH_3—CO.OH, or acetic acid.

373. Isomerism and its Varieties.—*Isomeric bodies* are those whose empirical formulæ, or percentage composition, are the same, and yet whose physical and chemical properties are different.

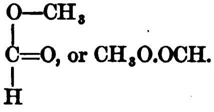
There are two kinds of isomerism, viz., *metamerism* and *polymerism.*

Metameric bodies are those whose molecular weights are the same, that is, those having the same number of similar atoms; such, for example, as acetic acid and methyl formate, substances possessing widely different properties and yet whose ultimate composition is the same, viz., $C_2H_4O_2$. This difference in properties is due to a difference in the atomic arrangement, which is probably represented by the following graphic formulæ, viz.:



$$\begin{array}{l} O{-}H \\ \vert \\ C{=}O, \text{ or } C_2H_3O.OH \\ \vert \\ CH_3 \end{array}$$

Acetic Acid.



$$\begin{array}{l} O{-}CH_3 \\ \vert \\ C{=}O, \text{ or } CH_3O.OCH. \\ \vert \\ H \end{array}$$

Methyl Formate.

Polymeric bodies are those whose percentage compositions are the same, but whose molecular weights are different. These bodies contain an unequal number of similar atoms. The molecular formulæ of polymeric bodies are usually whole multiples of one another; as, for example,

C_2H_4 = ethylene.
C_3H_6 = propylene.
C_4H_8 = butylene.
C_5H_{10} = amylene.

Here the percentage composition is the same in each case, viz., the ratio of 1 to 2; but the molecular weight and the actual number of the atoms differ; butylene, for example, containing in its molecules twice as many atoms of carbon and hydrogen as ethylene.

374. Homologous Series.—A *homologous series of compounds* is one whose formulæ differ by CH_2 or a whole multiple of CH_2. The physical and chemical properties of homologous bodies exhibit a marked similarity, especially when near one another in the series. These similarities are sufficiently close to enable us to assert the probable character of any member of a homologous series that may not as yet have been produced.

The constant addition of CH_2, or a multiple thereof, generally produces changes, that are very nearly proportional, in the boiling and melting points of the resulting compounds, as well as in their optical properties.

375. Action of Heat on Organic Substances.—When an organic compound is sufficiently heated out of contact with air, the affinity that holds its constituent parts together is thereby weakened, and it breaks up into other compounds that are more stable at high temperatures. Such a process is called *dry* or *destructive distillation*, and is generally effected by subjecting the substance to a red heat.

If the substance is nitrogenous, and the temperature be sufficient, the nitrogen is generally given off as ammonia. By mixing the substance with an excess of lime or potash, the regularity of the decomposition is greatly increased, and various acids are formed, which unite with the alkaline base.

376. Putrefaction, Decay, and Fermentation.—When certain organic substances are exposed to the action of moist air they undergo a decomposition, and evolve various gaseous products, which are generally of a disagreeable odor. This change is called *decay*, and is due to a gradual oxidation, followed by a rearrangement of the constituent elements.

Besides the action of the oxygen, the organic body is exposed to minute microscopic germs, obtained from the air, which are reproduced with surprising rapidity, and produce a change known as *putrefaction*, or *putrefactive decay*. In such cases many of the decomposition products must result from the excreta of these microscopic organisms.

Fermentation is a peculiar kind of putrefaction not attended by disagreeable odors, and resulting in the production of useful products. Yeast acts as a ferment. A very minute quantity of a ferment can produce change in a very large quantity of material.

In these changes the oxygen may act either by directly combining with the organic body, or by removing its carbon or hydrogen.

377. Classification of the Carbon Compounds.—The compounds of carbon can be conveniently arranged under four groups, according to the linking of the carbon nucleus, viz.:

I. *Single-Linked Carbon Nuclei.* This group includes the paraffines and their derivatives. These are *saturated compounds*, and can only receive additional elements by substitution.

II. *The Double- or Triple-Linked Carbon Nuclei*, or compounds containing less hydrogen than the preceding. They form *unsaturated compounds*, since they can combine directly with hydrogen, or the haloids, or their hydracids, and thus be made saturated by addition.

The compounds of the double- or triple-linked carbon nuclei are *satisfied*, or they could not exist in a free state. When they form compounds by the addition of simple or compound radicals, a break or rupture of one of the bonds of a doubly-linked carbon atom occurs.

The two preceding groups are sometimes called the *fatty group,* because they include the vegetable and animal fats.

III. *The Closed-Chain Carbon Nuclei,* or compounds containing relatively more carbon than the preceding. This group is sometimes called the *aromatic group,* because it contains in its series a number of aromatic bodies. The bodies of this group, in a few instances, act like the preceding, in forming products by mere addition.

IV. *Compounds of Unknown Constitution.* The members of this class include various vegetable and animal products, of such complex constitution that their structure has not as yet been ascertained. This class is constantly growing smaller and smaller.

SYLLABUS.

The innumerable compounds, or their derivatives, produced under the influence of animal and plant life, are formed by various combinations of carbon with other elements, and are called organic compounds.

Organic compounds were once believed to be formed only under the peculiar influence of vitality. It is now known, however, that most of these substances can be formed in the laboratory, by synthesis.

Organic chemistry treats of organic compounds, that is, organic chemistry is the chemistry of the carbon compounds.

The ultimate analysis of an organic compound may be effected in a variety of ways.

In the analysis of an organic compound which contains carbon, hydrogen, and oxygen, only the weight of the carbon and hydrogen is determined, and the difference gives the weight of the oxygen.

Liebig's method for determining hydrogen and carbon consists in heating a mixture of the substance and cupric oxide in a combustion-tube of hard glass. The carbon is converted into carbonic acid gas, and the hydrogen into water. These products are absorbed by caustic potash and calcium chloride respectively, and their amount determined from the increase in weight of the vessels containing the absorbent substances.

The combustion-tube is heated by a furnace containing charcoal, or by means of a series of Bunsen burners.

The calcium chloride is contained in a straight-bulbed tube, or in a U-shaped tube. Sometimes it is connected with a U-shaped tube filled with pumice-stone saturated with sulphuric acid.

The solution of potash is contained in a three-bulbed tube, so shaped as to insure the gas passing through the solution in the form of small bubbles.

The nitrogen of an organic compound is determined by burning the substance in a tube with cupric oxide, and measuring the volume of the nitrogen evolved; or by heating the substance with soda and lime, and converting the nitrogen into ammonia, and treating with platinum chloride. In this latter case, the ammonia is converted into an insoluble, double chloride of ammonium and platinum, which is washed, dried, and weighed for the estimation of its nitrogen.

The sulphur in an organic compound may be estimated by oxidizing it to sulphuric acid, by the action of nitric acid. The sulphuric acid is then converted into insoluble barium sulphate, from which the quantity of sulphur is afterwards estimated.

When the relative proportions in 100 parts of the constituent elements of a compound substance are known, the relative proportions of the different atoms may be determined by dividing the quantity of each substance by its atomic weight. By this means its empirical formula may be ascertained.

If the molecular weight of a compound is known, its empirical formula is readily ascertained.

The simplest method of determining the molecular weight is to ascertain the density of the gas or vapor as compared with hydrogen. The molecular weight is then equal to twice the density as compared with hydrogen. If the substance is not volatile, its molecular weight is determined by causing it to enter into a definite combination with some body like one of the metals, whose atomic weight is known.

An empirical formula is one that represents merely the nature and number of the constituent atoms.

A rational formula is one that represents the mode of formation of the compound, and consequently the mode of its decomposition.

Isomeric bodies are those whose empirical formulæ or percentage composition are the same, and yet whose physical and chemical properties are different. There are two kinds of isomerism, viz.: metamerism and polymerism.

Metameric bodies are those whose molecular weights are the same, that is, those containing the same number of atoms. The difference in properties of this class of isomeric bodies is due to a difference in the atomic arrangement.

Polymeric bodies are those whose percentage composition is the same, but whose molecular weights are different.

A homologous series of compounds is one whose formulæ differ by CH_2 or a whole multiple of CH_2.

Homologous compounds possess marked physical and chemical resemblances.

The basis or groundwork of the organic molecule is the tetrad element carbon.

The carbon nucleus may have its carbon atoms linked together in a variety of ways, either in simple chains or in closed chains or rings.

Organic substances whose carbon nuclei are in the form of simple chains, joined by a single bond, can only form new compounds by substitution. Those whose nuclei are joined by several bonds, may form new compounds by addition; that is, by one of the carbon bonds being freed.

An organic radical consists of an unsaturated carbon nucleus.

Methyl, ethyl, propyl, butyl, and amyl are compound organic radicals, having one free bond. They may combine among themselves, or with other compound radicals, such as hydroxyl, carboxyl, etc. When combined with hydroxyl, they form a class of bodies called alcohols; when combined with carboxyl, they form acids.

By the action of heat on an organic compound, in the absence of air, the compound breaks up into new compounds. This process is called dry or destructive distillation.

Organic compounds are decomposed in the presence of moist air. This decomposition is called decay when caused by a mere oxidation, and putrefaction when due to the multiplication of microscopic organisms, due to the germs of animals and plants obtained from the air.

Fermentation is a peculiar kind of putrefaction, due to the presence of a peculiar organism.

The carbon compounds may be divided into different classes, according to the character of the linking of the carbon nuclei. These classes are as follows, viz.:

1st. The single-linked carbon nuclei, or the saturated carbon compounds.

2d. The double- or triple-linked carbon nuclei, or the unsaturated carbon compounds.

3d. The closed-chain carbon nuclei, or the aromatic compounds.

4th. Compounds of unknown constitution.

QUESTIONS FOR REVIEW.

What element is common to all organic substances? What are the commonest elements in these substances?

Can organic substances be formed by synthesis, or are they only formed under the influence of the vital force?

Define an organic substance. Define organic chemistry.

What is meant by the immediate principles of an organic substance?

Define proximate analysis; ultimate analysis.

Describe Liebig's process for the estimation of the hydrogen and oxygen in an organic body.

By what different methods may the nitrogen in an organic body be estimated? How is the sulphur in an organic body estimated?

Explain the manner in which the empirical formula of an organic substance is determined from a knowledge of the percentage composition of its constituents.

Why is it much easier to determine the empirical formula when the molecular weight is known?

How is the molecular weight of an organic substance ascertained when the substance is volatile? How, when it is not volatile?

What is meant by isomeric bodies? What two kinds of isomerism are there?

Define metameric bodies; polymeric bodies.

What is the cause of the difference in properties possessed by metameric bodies?

What quantivalence has carbon?

Show, by means of graphic formulæ, one, two, three, four, and five carbon atoms completely saturated with hydrogen atoms. What names are given to these respective compounds?

Show, by means of graphic formulæ, two, three, four, and five carbon atoms incompletely saturated with hydrogen, and yet able to exist in a free state.

What is meant by a carbon nucleus? Show, by means of a graphic formula, a carbon nucleus containing a single chain; show one containing a closed chain or ring. Which of these would contain relatively the greater proportion of carbon, when its free bonds are closed or saturated? Why?

Define saturated compounds. Unsaturated compounds. How may new compounds be formed from saturated compounds? How may they be formed from unsaturated compounds?

What is meant by a compound radical? How does a compound radical differ from an unsaturated organic compound?

Write graphic formulæ for the compound radicals methyl, ethyl, propyl, butyl, and amyl.

Show, by means of graphic formulæ, the composition of the various alcohols derivable from the preceding compound radicals.

Show, by means of graphic formulæ, the manner in which organic acids are derived from these compound radicals.

What is meant by a rational formula? Define a homologous series.

What is the nature of the action which heat exerts on an organic body not in contact with air? Define destructive or dry distillation.

What is the difference between decay and putrefaction? Define fermentation.

Name the four principal classes into which all organic compounds may be divided.

SECTION II.

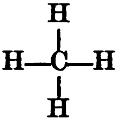
SINGLE-LINKED CARBON NUCLEI.

CHAPTER II.

CYANOGEN, ITS COMPOUNDS AND DERIVATIVES.

378. Composition of Cyanogen.—When the tetradic carbon atom is united with the triadic nitrogen atom, it still has one of its bonds unsatisfied. In this state it forms the compound radical called *cyanogen*, viz., $—C \equiv N$. This substance is capable of existing in a free state by combining with itself, thus, $N \equiv C—C \equiv N$, and then forms gaseous cyanogen.

The radical cyanogen may be regarded as marsh gas, in which an atom of nitrogen replaces three hydrogen atoms, and the remaining atom of hydrogen is absent. Cyanogen and its compounds will be more conveniently treated before the discussion of the hydrocarbons.



$$\begin{array}{ccc} & H & \\ & | & \\ H— & C & —H \\ & | & \\ & H & \end{array}$$

Marsh Gas.

379. Formation of Cyanogen and its Properties.—When potassium carbonate, mixed with excess of carbon, is heated to redness in an atmosphere of nitrogen, the carbon and nitrogen combine to form cyanogen, which at once unites with the potassium of the carbonate, thus:

$$K_2CO_3 + 4C + N_2 = 3CO + 2KCN$$

Potassium Carbonate + Carbon + Nitrogen = Carbon Monoxide + Potassium Cyanide.

Cyanogen may also be produced by heating a nitrogenous substance, ammonia for example, with potassium carbonate;

or by passing ammonia gas over red-hot charcoal, when the following reaction occurs, viz.:

$$\underset{\text{Carbon}}{C} + \underset{\text{Ammonia}}{2NH_3} = \underset{\text{Ammonium Cyanide}}{NH_4CN} + \underset{\text{Hydrogen.}}{H_2}$$

In order to obtain cyanogen in the gaseous state, mercury cyanide is heated in a small test-tube fitted with a cork pierced by a glass jet. Cyanogen gas is evolved, and may be ignited and burned, producing carbon dioxide and nitrogen.

Cyanogen is a colorless and highly poisonous gas, possessing a strong smell of bitter almonds. It is soluble in water, and must, therefore, be collected over mercury. Cyanogen combines directly with the metal potassium, with the evolution of light and heat, producing potassium cyanide.

380. Hydrocyanic Acid, HCN, or *Prussic Acid.*—The radical cyanogen combines with hydrogen and forms hydrocyanic or prussic acid, $H—C \equiv N$.

Hydrocyanic acid is most conveniently prepared by the action of dilute sulphuric acid on the yellow prussiate of potash (potassium ferrocyanide). The mixture is placed in a flask provided with a tightly-fitting glass tube connected with a receiver. Water vapor and hydrocyanic acid are evolved and condensed.

The acid is separated from the water in which it is dissolved by *fractional distillation.*

Hydrocyanic acid is a colorless, mobile, and very volatile liquid, possessing a peculiar odor, resembling that of bitter almonds. It burns in the air with a pale-violet flame.

Hydrocyanic acid is excessively poisonous. Diluted with a large quantity of air and inhaled to but a trifling extent it causes a peculiar feeling in the throat, and in larger quantities causes drowsiness, followed by death. The student is recommended not to experiment with the cyanogen compounds until proficient in chemical manipulations.

Hydrocyanic acid does not possess very pronounced acid properties; it forms cyanides and water with the metallic oxides. It forms prussian blue when added to the oxides of iron, and can readily be recognized in this way. It also gives, with a silver salt, a white precipitate, that does not darken on exposure to the light.

381. Metallic Cyanides.—Hydrocyanic acid combines directly with the positive metals to form cyanides.

Potassium cyanide, KCN. Besides the method already described for producing this substance directly, it can most conveniently be prepared by the action of heat on dried potassium ferrocyanide. The black mass, which remains after the process, is treated with alcohol, and potassium cyanide is obtained in the form of a white, deliquescent, crystalline salt. It has an alkaline taste and reaction, and is excessively poisonous. It is quite soluble in water, and is largely employed in electro-metallurgy and in photography.

Barium, *calcium*, and *strontium cyanides* may be obtained directly by acting on their hydrates by hydrocyanic acid.

Zinc and *silver cyanides* may be obtained by the action of potassium cyanide on any of their salts.

Mercury cyanide, $Hg(CN)_2$, is obtained by neutralizing hydrocyanic acid with mercuric oxide. It crystallizes in colorless, anhydrous prisms, and is very poisonous.

The cyanides are very apt to form double salts by direct combination. This is done by one of the bonds between the carbon and the nitrogen being liberated. Potassium cyanide dissolves many of the insoluble metallic cyanides and forms double salts.

382. Ferrocyanogen and Hydro-Ferrocyanic Acid.—A very important compound radical, containing iron and cyanogen, is formed by a dyad iron atom combining with six groups of cyanogen. This radical is called *ferrocyanogen*, and is tetradic; when its four free bonds are satisfied by hydrogen, *hydroferrocyanic acid*, $H_4Fe(C_6N_6)$, is formed.

383. Potassium Ferrocyanide, $K_4(C_6N_6)Fe + 3H_2O$, or

Yellow Prussiate of Potash.—This very important salt is obtained by strongly calcining animal refuse matters, such as blood, leather, horn, etc., in closed iron vessels with potassium carbonate. Potassium cyanide is formed, and, on the addition of ferrous sulphate to the solution obtained by treating the fused mass with water, yields, on evaporation, crystals of ferrocyanide of potassium.

Potassium ferrocyanide crystallizes in splendid lemon-yellow crystals, which are modified square octahedra, possessing a marked cleavage. They are unalterable in air, but lose their water of crystallization on being heated, and become opaque and white.

Potassium ferrocyanide is very much employed in the laboratory as a reagent. It yields precipitates with nearly all the heavy metals, which may either partly or wholly replace the potassium. It is soluble in water, and is not poisonous.

Prussian blue, $(Fe_2)_2(C_6N_6Fe)_3$, is a very important blue pigment obtained by precipitating a ferric salt by potassium ferrocyanide. It is insoluble in water, but soluble in oxalic acid, the solution in which is used as a blue ink.

384. Potassium Ferricyanide, $K_6(C_6N_6Fe)_2$, or *red prussiate of potash,* is obtained by passing chlorine through a solution of potassium ferrocyanide. The following reaction occurs, viz.:

$$\begin{array}{ccccccc} 2K_4(C_6N_6)Fe & + & Cl_2 & = & 2KCl & + & K_6(C_6N_6Fe)_2 \\ \text{Potassium Ferrocyanide} & + & \text{Chlorine} & = & \text{Potassium Chloride} & + & \begin{array}{c}\text{Potassium}\\ \text{Ferricyanide.}\end{array} \end{array}$$

The action of the chlorine in this case has been to merely remove two atoms of potassium.

Potassium ferricyanide contains the hexad radical ferricyanogen, formed by the union of two ferrocyanogen radicals.

Potassium ferricyanide crystallizes in splendid shining red rhombic prisms, which, dissolved in water, produce a very poisonous, dark, yellowish-green solution. This solution has no action on ferric salts, but produces, with ferrous salts, a blue precipitate, called *Turnbull's blue*, similar to Prussian blue.

Hydroferricyanic acid, $H_6Fe_2(C_6N_6)_2$, is obtained by the action of sulphuric acid on a ferricyanide. It forms numerous salts called ferricyanides.

385. **Sodium Nitroferrocyanide,** $Na_2(CN)_5(NO)Fe + 2H_2O$, or *sodium nitroprusside*, is formed by the action of dilute nitric acid on ferrocyanide of potassium, and the addition of sodium carbonate to the liquor that remains after all its crystallizable salts have been deposited. This salt crystallizes in reddish prisms, and produces in water a red-brown solution. This solution is employed as a delicate test for the alkaline sulphides, with which it forms a deep purple.

386. **Compounds of Cyanogen with the Haloids.**—The radical cyanogen unites with the negative elements of the haloids, to which it plays the part of a positive radical.

Liquid cyanogen chloride, CNCl, is obtained by the action of chlorine on mercury cyanide. It is a colorless liquid of a very unusually poisonous character.

Solid cyanogen chloride, $C_3N_3Cl_3$, is a modified form of the liquid chloride. It crystallizes in large yellow needles.

Cyanogen iodide, CNI, and *Cyanogen bromide*, CNBr, are obtained by dissolving iodine or bromine in potassium cyanide. They are very poisonous crystalline solids.

387. **Cyanic Acid,** $O{=}C{=}N{-}H$, is obtained by submitting an acid called cyanuric acid to dry distillation, thus,

$$\underset{\text{Cyanuric Acid}}{C_3O_3N_3H_3} \quad = \quad \underset{\text{Cyanic Acid.}}{3HOCN}$$

Cyanic acid, when condensed by a freezing mixture, is a colorless, volatile liquid, having a peculiar irritating odor, somewhat like that of acetic acid. It is very unstable, and when removed from the freezing mixture is converted into a white amorphous mass, called *cyamelide*.

388. **Cyanates.**—*Potassium cyanate*, KOCN, is obtained by

melting dry plumbic oxide with potassium cyanide. It is a colorless, transparent salt, that is soluble in water.

Ammonium cyanate is formed when the vapor of cyanic acid is passed into ammonia. It is a white substance, whose solution in water, when boiled or abandoned for several days, is transformed into urea.

$$\underset{\text{Ammonium Cyanate}}{(NH_4)OCN} = \underset{\text{Urea.}}{CO\begin{matrix}-NH_2\\-NH_2\end{matrix}}$$

389. Potassium Sulphocyanate, KSCN, or the so-called *potassium sulphocyanide,* may be regarded as potassium cyanate, in which the oxygen is replaced by sulphur. It is obtained by heating potassium ferrocyanide with half its weight of flowers of sulphur. The fused mass is treated with water, filtered, and potassium carbonate added until ferrous carbonate is no longer precipitated. The residue, left by completely evaporating the filtered liquid, is dissolved in alcohol, and deposits transparent, deliquescent, striated, needle-shaped crystals.

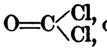
This salt produces a deep, blood-red liquid with ferric salts.

Experiment 84.—Pour a few drops of a dilute solution of ferric chloride on a white dinner-plate, and add a few drops of a solution of potassium sulphocyanate. The plate will appear to be spotted with fresh blood.

Experiment 85.—Dip the end of a finger into a strong solution of ferric chloride. Dissolve sufficient potassium sulphocyanate in a tumblerful of clear water to make a moderately strong solution. Dip the finger in this liquid, and blood will appear to flow from the finger.

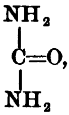
390. Derivatives of the Radical Carboxyl $=C=O$.—The radical *carboxyl* forms the following compounds, viz.:

$O{=}C{=}O$, or Carbonic acid.



$O{=}C\begin{matrix}\diagup Cl,\\ \diagdown Cl,\end{matrix}$ or Chlorocarbonic acid.

$O{=}C{=}N{-}H$, or Cyanic acid.



$$\begin{matrix}NH_2\\|\\C{=}O\\|\\NH_2\end{matrix}$$ or Urea.

Urea may therefore be considered to be formed from two ammonia molecules by the substitution of the compound radical carbonyl for two atoms of hydrogen.

391. Urea, CON_2H_4, is one of the constituents of the urine of animals. It may be prepared artificially by the action of heat on ammonium cyanate as already explained. Its presence in animals results from the waste of nitrogenous tissues. It is excreted from the blood by the kidneys.

Pure urea crystallizes in transparent, colorless, four-sided prisms, that are devoid of odor, and have a cooling taste like nitre. They are very soluble in water, and form compounds with acids, such, for example, as *urea hydrochloride*, CON_2H_4,HCl, and *urea nitrate*, CON_2H_4,HNO_3. It also forms numerous salts with the metallic oxides. By the action of heat, urea is decomposed into ammonia and *cyanuric acid*, $C_3O_3N_3H_3$.

Compound ureas are formed by the radicals methyl, ethyl, propyl, butyl, and amyl, replacing some of the hydrogen atoms in urea. They are called *methyl-urea*, *ethyl-urea*, etc.

CHAPTER III.

SINGLE-LINKED CARBON NUCLEI (Continued).

THE PARAFFINES, OR THE MARSH-GAS SERIES.

392. Homologous Series, C_nH_{2n+2}.—In this series, the carbon nuclei are single linked, and all the free bonds of the carbon atoms are saturated with hydrogen; therefore there are always twice as many hydrogen atoms, plus two, as there are carbon atoms, *i. e.*, their general formula is C_nH_{2n+2}.

Names.	Formulæ.	Boiling points.	Names.	Formulæ.	Boiling points.
Methane . .	CH_4	Gas.	Heptane. . .	C_7H_{16}	209°F.
Ethane . . .	C_2H_6	Gas.	Octane . . .	C_8H_{18}	257°
Propane . .	C_3H_8	Gas.	Nonane . . .	C_9H_{20}	298°
Butane . . .	C_4H_{10}	34°F.	Decane . . .	$C_{10}H_{22}$	386°
Pentane. . .	C_5H_{12}	100°	Endecane . .	$C_{11}H_{24}$	532°
Hexane . . .	C_6H_{14}	158°			

The members of this series pass gradually from gases to volatile liquids, and finally to crystalline solids. *Paraffine,* which gives the name to the series, is a mixture of various solids of the series.

Paraffines are tasteless and inodorous, and are unattacked in the cold by the strongest acids, but when heated with nitric or chromic acid, are slowly oxidized.

The American petroleums, or coal-oils, consist of a mixture of the above series, the gases and solids being dissolved in the liquids. In boring for coal-oil, large quantities of inflammable gases escape, consisting principally of marsh-gas, ethane, and hydrogen.

393. Methane, CH_4, or *marsh-gas*, is an inflammable gas, that is disengaged in an impure state from marshy soils, whence it is derived from the decomposition of vegetable matter. It is also disengaged from the veins in coal mines, where it forms the dreaded *fire-damp*.

Methane may be prepared artificially by the action of heat on a glass flask containing sodium acetate mixed with an excess of caustic alkali; a little lime is added to prevent the alkali acting on the glass.

$$\begin{array}{ccccccc} NaC_2H_3O_2 & + & NaOH & = & CH_4 & + & Na_2CO_3 \\ \text{Sodium Acetate} & + & \text{Sodium Hydrate} & = & \text{Methane} & + & \text{Sodium Carbonate.} \end{array}$$

Methane is a colorless gas, having a density of 0.559. It burns in the air with a yellow flame, and mixed with air or oxygen explodes violently on the approach of a flame. It is not poisonous, being breathed in a diluted state by miners without any apparently injurious effect.

Ethane, C_2H_6, is a colorless, odorless gas, that burns in the air with a slightly luminous flame.

Propane, C_3H_8, is a colorless gas, readily condensed into a colorless liquid by intense cold.

394. Petroleum, or Coal-Oil, consists of a mixture of the various members of the paraffine group. It varies in color from a colorless or slightly yellowish liquid, with a bluish lustre, to a greenish or dark-brown viscid liquid somewhat resembling tar or pitch. It occurs in various parts of the world, but nowhere in such prodigious quantities as in Western Pennsylvania.

The volatile gases and vapors that are given off during the distillation of the crude oil are condensed, and form very volatile liquids, called *cymogene* and *rhigolene*. These products are employed for the production of artificial cold, which they occasion by means of their rapid evaporation.

The products whose boiling-points are somewhat higher—up to about 328° F.— are called *gasoline*, *naphtha*, and *benzine*. Their vapors, mixed with air, are employed in gas machines for forming cheap illuminating gas. They form a cheap solvent for rubber, fats, and other substances, and are employed in paints as a substitute for turpentine.

Owing to the liability of the vapors of the above substances to form an explosive mixture with air, the sale of petroleum for use in lamps is forbidden when it gives off a combustible vapor at a temperature of 140° F., or under.

Solid paraffines can be obtained from petroleum by the action of nitric acid.

395. Fractional Distillation.—When a mixture containing several liquids, whose boiling-points are considerably different, is cautiously heated to the boiling-point of the most volatile liquid, the latter is vaporized, and may be separated from the remaining liquids. If the remaining liquids be heated to the boiling-point of their most volatile liquid, this latter passes off, and may be thus separated from the others. This process is called *fractional distillation*, and may be employed for the separation of the different members of the series.

When, however, the difference between the respective boiling-points is inconsiderable, the process is rendered difficult by some of the less volatile liquids passing off with the more volatile ones. In this case the operation is carried on very slowly, care being taken to prevent an increase of temperature. By introducing a series of bulbs, *a*, *a′*, etc., in the delivery-tube, provided with side tubes, *b*, *b′*, etc., Fig. 137, the mixed vapors are cooled by contact with the cool walls of the bulb, so that the less volatile portions are condensed, and flow back into the retort. The uncondensed vapor is then condensed by any suitable means.

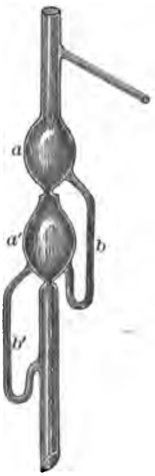
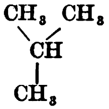


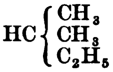
Fig. 137. Fractional Distilling Apparatus.

396. Substitution Compounds of the Paraffines.—As we have already seen, the saturated hydrocarbons of this group may form an immense variety of compounds, by having one or more of their hydrogen atoms replaced by single atoms of other elements, or by any of the compound radicals. We can only mention a few of these, thus:

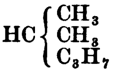


= Trimethylmethane.

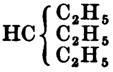
So also:



$$HC\begin{cases} CH_3 \\ CH_3 \\ C_2H_5 \end{cases} = \text{Dimethylethylmethane.}$$



$$HC\begin{cases} CH_3 \\ CH_3 \\ C_3H_7 \end{cases} = \text{Dimethylpropylmethane.}$$



$$HC\begin{cases} C_2H_5 \\ C_2H_5 \\ C_2H_5 \end{cases} = \text{Triethylmethane.}$$

So also,

CH_3Br =	Methyl bromide.	$C_5H_{11}Br$ =	Amyl bromide.
CH_3I =	" iodide.	$C_5H_{11}I$ =	" iodide.
CH_3Cl =	" chloride.	$C_5H_{11}Cl$ =	" chloride.

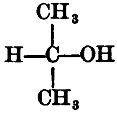
397. The Alcohols are combinations of the compound radicals methyl, ethyl, propyl, butyl, amyl, etc., which are sometimes called the *alcohol radicals*, with hydroxyl; thus,

CH_3OH =	Methylic	alcohol,	or methyl	hydrate.
C_2H_5OH =	Ethylic	"	" ethyl	"
C_3H_7OH =	Propylic	"	" propyl	"
C_4H_9OH =	Butylic	"	" butyl	"
$C_5H_{11}OH$ =	Amylic	"	" amyl	"
$C_6H_{13}OH$ =	Hexylic	"	" hexyl	"
$C_7H_{15}OH$ =	Heptylic	"	" heptyl	"
$C_8H_{17}OH$ =	Octylic	"	" octyl	"
$C_9H_{19}OH$ =	Nonylic	"	" nonyl	"

These alcohols are called the *primary alcohols*, in order to distinguish them from the secondary and tertiary alcohols.

The primary alcohols are converted by oxidation into bodies called *aldehydes* by one atom of oxygen, and into monobasic acids by two atoms of oxygen.

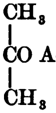
Secondary alcohols are substitution compounds in which one of the carbon bonds is saturated by the radical hydroxyl, and two other bonds by the alcohol radicals; thus,



$$\begin{array}{c} CH_3 \\ | \\ H—C—OH \\ | \\ CH_3 \end{array}$$

Secondary Propylic Alcohol.

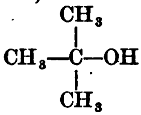
By oxidation one oxygen atom removes two hydrogen atoms from the secondary alcohols, and produces a class of bodies called *ketones*. Thus,



$$\begin{array}{l} CH_3 \\ | \\ CO \\ | \\ CH_3 \end{array}$$

Acetone, or Ketone.

Tertiary alcohols are substitution compounds in which all the hydrogen atoms are replaced—three by alcohol radicals and one by hydroxyl; thus,



$$\begin{array}{c} CH_3 \\ | \\ CH_3—C—OH \\ | \\ CH_3 \end{array}$$

Tertiary Butylic Alcohol.

398. Methylic Alcohol, CH_3OH, or wood-spirit, is formed as one of the products of the dry distillation of wood, or other organic materials. It is now largely obtained as a by-product in the preparation of beet-sugar.

When pure, methylic alcohol is a colorless, mobile liquid, having a peculiar vinous odor. Its density is 0.81, and its boiling-point is 152° F. It is inflammable, burning in air with a pale-blue flame. It is largely employed as a solvent for gums and resins, and in the manufacture of the aniline colors.

399. Ethylic Alcohol, C_2H_5OH, or *common alcohol*, is obtained by the fermentation of glucose, or substances readily transformed into glucose. It was originally obtained by the distillation of wine, but is now obtained from malted grain, potatoes, sugars, molasses, and various fruits. The preceding substances are first fermented by means of yeast, and the alcohol so formed separated by distillation, and strengthened by redistillation.

In order to obtain it free from water, or in the form of *absolute alcohol*, it is distilled over substances possessing a strong attraction for water, such as quicklime.

Pure alcohol is a mobile, colorless liquid, possessing a vinous odor. Its density is 0.809, and its boiling-point 173° F. It has a strong attraction for water, and mixes with it in all proportions, with a contraction of volume, and consequent elevation of temperature.

Alcohol is employed in medicine as a stimulant. Its excessive use is sadly detrimental to health, and generally shortens life. It has marked solvent powers, dissolving gases, liquids, and solids. The *tinctures* of the apothecary are alcoholic solutions of various medicinal substances. Alcohol also dissolves various fats and oils.

Alcohol burns in air with a pale-blue flame, and is extensively used for its heating powers. It is largely used for the manufacture of ordinary ether. It is used for a solvent, and for the preservation of anatomical specimens.

All fermented liquors, such as wine, beer, ale, cider, etc., contain alcohol.

The quantity of alcohol present in any fermented liquid is determined by means of an instrument called an alcoholimeter, which gives the density of the liquid.

The other alcohols are also produced in varying quantities during the fermentation of saccharine liquids. They are comparatively unimportant. *Fusel oil* contains amylic alcohol.

400. Vinous Fermentation.—In the manufacture of wine, the juice of the grape is left in vats, in which it undergoes spontaneous fermentation. The ferment is derived from the vegetable albumen, that, by absorbing oxygen from the air, ferments and gradually converts the sugar into alcohol. *Dry wines* contain little or no sugar; *sweet wines* are such as have part of their sugar unchanged. *Champagnes* are bottled before the fermentation is completed, and therefore contain carbonic acid gas, or are effervescing.

The vats in which the fermentation takes place contain a hard deposit called *argol*, which is mainly composed of potassium tartrate.

Beer is a fermented liquor obtained from *malt*, or artificially germinated grain. The grain, generally barley, is *malted* by being steeped in water and spread in a heap on a floor, where it generates heat and germinates. The grain is occasionally turned to prevent excessive heating, and when sufficiently germinated further growth is checked by drying in a kiln. A peculiar ferment called *diastase* is produced during germination, and converts part of the starch of the grain into sugar. The malt is then extracted by being steeped in warm water, which dissolves the sugar and some nitrogenized matter, and the solution is fermented by the addition of a small quantity of yeast.

During the fermentation, the ferment, or *yeast*, increases in amount and collects on the surface. Yeast is an organized substance—a peculiar kind of fungus, produced from the soluble nitrogenous portion of the grain. Added to the dough of bread, it causes it to rise, by converting a small quantity of the sugar of the flour into alcohol and carbonic acid gas. It is this latter gas that makes the bread light by distending the dough into bubbles.

401. Ethers, or Oxides of the Alcohol Radicals.—These bodies are formed by two alcohol radicals being united by an oxygen atom; or we may regard them as alcohols in which the hydrogen atom of the hydroxyl is replaced by an alcohol radical. *Simple ethers* are those containing the same radical so united; *mixed ethers* are those containing two different radicals so united.

The ethers may be obtained by the action of sulphuric acid on the corresponding alcohol. They are liquids that as a class are insoluble, or nearly so, in water, and have boiling points lower than those of the alcohols from which they are derived.

402. Methylic Ether, $CH_3.O.CH_3$, is obtained by distilling a mixture of methylic alcohol with four times its weight of sulphuric acid. The evolved vapors are passed through a solution of caustic potash, and the methylic ether, which is unabsorbed, condensed in a receiver, cooled by a powerful freezing-mixture. At very low temperatures it is a colorless liquid, and at ordinary temperatures a gas.

403. Ethylic Ether, $C_2H_5.O.C_2H_5$, or *Ether*, the most important of these compounds, is made by distilling a mixture of 5 parts of 90 per cent. alcohol and 9 parts of strong sulphuric acid in the flask A, Fig. 138, containing a thermometer, *a*, designed to prevent the temperature from rising beyond 293° F. The vapor evolved passes through the exit-tube, *b*, when it is condensed by the Liebig's condenser, B, and collected in the vessel C. As the sulphuric acid undergoes no change, the process can be rendered continuous by occasionally introducing fresh alcohol from the vessel D, through the funnel-tube, *d*. In practice, however, the sulphuric acid can only produce the change in a certain quantity of alcohol.

The distilled product contains alcohol and a little sulphurous acid. It is purified by washing first with caustic lime and afterwards with pure water, and is then distilled over calcium chloride.

There are two changes that occur during the etherification, viz.:

$$\underset{\text{Alcohol}}{C_2H_5.OH} + \underset{\text{Sulphuric Acid}}{H_2SO_4} = \underset{\text{Ethylsulphuric Acid}}{C_2H_5.HSO_4} + \underset{\text{Water.}}{H_2O}$$

Then, by the action of the ethylic sulphuric acid on alcohol, we have

$$\begin{array}{ccccccccc} C_2H_5.HSO_4 & + & C_2H_5.OH & = & C_2H_5.O.C_2H_5 & + & H_2SO_4 \\ \text{Ethyl Sulphuric Acid} & + & \text{Alcohol} & = & \text{Ether} & + & \text{Sulphuric Acid.} \end{array}$$

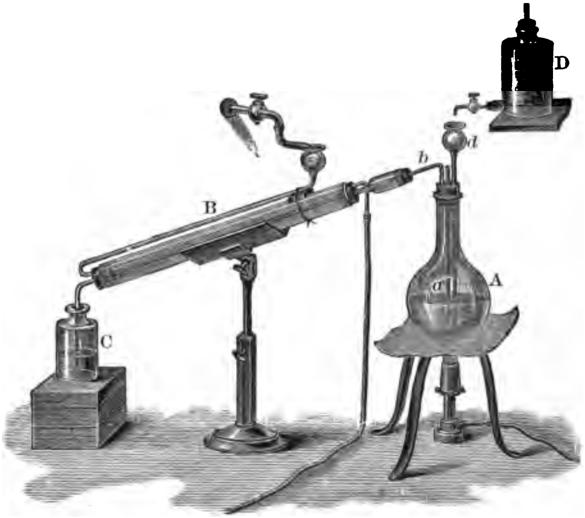


Fig. 138.—The Continuous Process for the Manufacture of Ether.

404. Properties and Uses of Ether.—Ether is a mobile, colorless liquid, possessing a peculiar penetrating odor. Its sp. gr. is 0.736, and its boiling-point 94° F. It evaporates rapidly on exposure to the air, thus producing a decided lowering of the temperature. It burns in the air with a luminous flame, and produces an explosive mixture when its vapor mingles with air in certain proportions.

Ether possesses marked solvent powers. It dissolves various gums, fats, oils, and resins, bromine and iodine, sulphur and phosphorus, and many of the metallic chlorides. It floats on the surface of water, with which it mixes but slightly. With alcohol, however, it mixes in all proportions.

The uses of ether are mainly dependent on its great solvent powers; it is also used in the preparation of collodion. Its great volatility has also caused it to be used in ice machines, as well as in surgery to produce local anæsthesia (insensibility to pain). This latter is obtained by directing a spray of the liquid on the part to be benumbed by the cold. When ether vapor is inhaled in sufficient quantity it produces complete anæsthesia.

Various substitution products are produced by the action of chlorine on ether.

The ethers of the remaining alcohols are comparatively unimportant.

405. Ethereal Salts, sometimes called *Compound Ethers.*—The alcohols, when mixed with strong acids, react therewith, and produce a class of salts of the alcohol radicals. A few of these will serve as examples for the rest.

The nitrates are formed by the action of very strong nitric acid on the alcohols. To prevent the oxidizing action of the acid, the action occurs in a vessel cooled by a powerful freezing-mixture; and, in order to prevent the liberation of nitrous acid, urea is previously added to the alcohol.

Methylic nitrate, $CH_3.NO_3$, a colorless heavy liquid.

Ethylic nitrate, $C_2H_5.NO_3$, is a colorless liquid of a pleasant odor. The vapors of both of these liquids decompose explosively if heated.

The nitrites are obtained by passing nitrous anhydride vapor into cooled alcohol.

Ethylic nitrite, $C_2H_5.NO_2$, mixed with ethylic alcohol and some of the oxidation products thereof, forms the well-known *sweet spirits of nitre,* used in medicine.

Besides these, there are ethyl, methyl, propyl, butyl, and amyl sulphates, sulphites, borates, silicates, phosphates, etc.

406. Action of Sulphur on the Alcohol Radicals.—The compound radical —SH may take the place of the hydroxyl in the alcohols, thus producing a class of bodies called the *mercaptans,* or the *thio-alcohols.* Such bodies are alcohols in which the oxygen atom is replaced by an atom of sulphur.

Ethylic mercaptan, $C_2H_5.SH$, or *ethyl-sulphydrate*, may be prepared by passing ethyl chloride vapor into potassium sulphydrate dissolved in alcohol, thus:

$$\underset{\text{Potassium Sulphydrate}}{KSH} + \underset{\text{Ethyl Chloride}}{C_2H_5Cl} = \underset{\text{Potassium Chloride}}{KCl} + \underset{\text{Ethyl Mercaptan.}}{C_2H_5SH}$$

Ethyl mercaptan is a colorless, mobile liquid, possessing a remarkably fetid odor. Its density is 0.835.

There is also a class of salts resembling the ethers, in which the oxygen atom in the ethers is replaced by a sulphur atom, as in *ethyl sulphide*, $C_2H_5.S.C_2H_5$, a colorless liquid having a marked odor of garlic.

407. Nitrogen Compounds of the Alcohol Radicals.—The alcohol radicals may combine with nitrogen by displacing one, two, or three of the hydrogen atoms in ammonia, NH_3. The bodies thus formed are called *amines*, or *compound ammonias*, and resemble ammonia in their general properties. Primary, secondary, and tertiary amines are those in which one, two, and three of the hydrogen atoms are respectively replaced. They are generally prepared from the iodide of the alcohol radical by heating it, under pressure, with ammonia, thus:

$$C_2H_5I + N\left\{\begin{matrix} H \\ H \\ H \end{matrix}\right. = N\left\{\begin{matrix} C_2H_5 \\ H \\ H \end{matrix}\right. + HI$$

Ethyl Iodide + Ammonia = Ethylamine + Hydriodic Acid.

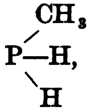
The amines precipitate many salts of the metals, and form salts by direct combination with acids.

The alcohol radicals may also replace the hydrogen atoms in the ammonium compounds; thus,

$N(CH_3)_3(C_2H_5)I$ = Trimethylethylammonium iodide.

408. Phosphorus Compounds of the Alcohol Radicals.—The alcohol radicals may combine with phosphorus by replacing one, two, or three hydrogen atoms in PH_3, thus producing *primary, secondary*, or *tertiary phosphines*. The latter combine with hydriodic acids to form *phosphonium iodides*.

The primary phosphines possess a fearful odor. They oxidize rapidly on exposure to the air, and often inflame spontaneously. They unite directly with carbon disulphide and sulphur to form liquid compounds.

Methyl phosphine,

$$P\begin{cases}CH_3\\H\\H\end{cases}$$
is a colorless gas.

The secondary phosphines are light, colorless liquids, possessing a penetrating odor, and ignite spontaneously on exposure to the air.

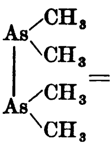
Dimethyl phosphine, $P(CH_3)_2H$, is a colorless liquid, that inflames spontaneously on exposure to the air.

Trimethyl phosphine, $P(CH_3)_3$, is a colorless mobile liquid, that inflames spontaneously on exposure to the air.

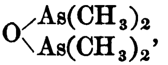
409. Arsenic Compounds with the Alcohol Radicals.—The alcohol radicals may combine with arsenic by replacing the three atoms of hydrogen in AsH_3, thus producing *tertiary arsines.*

Trimethyl arsine, $As(CH_3)_3$, is a colorless mobile liquid.

Arsenic sometimes combines with two alcohol radicals, and thus forms a radical which, by combining with a similar radical, can exist in a free state; thus,


$$\begin{matrix}As\begin{cases}CH_3\\CH_3\end{cases}\\|\\As\begin{cases}CH_3\\CH_3\end{cases}\end{matrix}$$
= Diarsentetramethyl or Cacodyl.

These bodies are called *cacodyls* (κακός, bad, and ὀδεῖν, smell), in reference to their fearful smell. The methyl cacodyl described above is a transparent, colorless liquid, spontaneously inflammable on exposure to the air. It is very poisonous.


$$O\begin{cases}As(CH_3)_2\\As(CH_3)_2\end{cases}$$

Cacodylic oxide, $O\begin{cases}As(CH_3)_2\\As(CH_3)_2\end{cases}$, or alkarsin, is an excessively poisonous, inflammable, and fearfully smelling liquid, whose vapor causes distressing nausea and vomiting.

SYLLABUS.

The compound radical cyanogen, $-C \equiv N$, may be regarded as methane, in which three hydrogen atoms are replaced by the triad atom nitrogen, and the fourth hydrogen atom is absent.

The molecule of free cyanogen is formed by the combination of two cyanogen radicals.

Cyanogen is formed when carbon and potassium carbonate are heated to redness in an atmosphere of nitrogen, or when a nitrogenous substance is heated with potassium carbonate.

Free cyanogen may be obtained by the action of heat on mercury cyanide. It is a colorless and very poisonous gas, that has an odor of bitter almonds, and burns in the air with a pale flame.

Hydrocyanic, or prussic acid, HCN, is obtained by the action of weak sulphuric acid on the yellow prussiate of potash. It is a colorless, mobile, volatile, and exceedingly poisonous liquid, having an odor of bitter almonds.

Hydrocyanic acid combines directly with the positive metals, producing bodies called cyanides.

Potassium cyanide, KCN, may be obtained by the action of heat on potassium ferrocyanide.

Barium, calcium, and strontium cyanides may be obtained by the direct action of hydrocyanic acid on their hydrates.

The cyanides combine with one another, and form double salts.

The compound radical ferrocyanogen is formed by a dyadic iron atom combining with six cyanogen radicals.

Potassium ferrocyanide is obtained by calcining refuse animal matters in closed vessels with potassium carbonate. The potassium cyanide so formed is converted into ferrocyanide by the addition of ferrous sulphate.

Potassium ferrocyanide, or yellow prussiate of potash, crystallizes in splendid yellow octahedra. It is extensively employed in the laboratory as a reagent.

Prussian blue is a valuable pigment obtained by precipitating a ferric salt by prussiate of potash. Dissolved in oxalic acid it forms a blue ink.

Potassium ferricyanide, or red prussiate of potash, is formed by passing chlorine through a solution of the yellow prussiate.

Potassium ferricyanide crystallizes in shining, red prisms, and is employed as a test for ferrous salts, with which it gives a blue precipitate called Turnbull's blue. Unlike the yellow prussiate, it is poisonous.

Sodium nitroprusside, or nitroferrocyanide, is obtained by the action of dilute nitric acid on the yellow prussiate. After all the crystallizable salts have separated, sodium carbonate is added, and the nitroprusside crystallizes. It is used as a delicate test for the alkaline sulphides, with which it gives a rich, evanescent, purple color.

The radical cyanogen combines with the haloids forming cyanogen chlorides, bromides, and iodides.

Cyanic acid, HOCN, or $O=C=N-H$, forms a class of salts called cyanates.

Potassium sulphocyanate, or sulphocyanide, is formed by heating potassium ferrocyanide with half its weight of flowers of sulphur. It forms a blood-red liquid with ferric salts.

The compound radical carbonyl, $=C=O$, may be regarded as forming cyanic acid, by uniting with the radical $=NH$.

Urea may be regarded as formed by two ammonia radicals, combined with carbonyl by the replacement of one of the hydrogen atoms in each. It occurs in the urine of animals as a result of the waste of nitrogeneous tissues. It is decomposed by heat into cyanuric acid.

Urea combines with the alcohol radicals to form methyl-urea, etc., or compound ureas.

In the hydrocarbons of the marsh-gas series, or the paraffines, the carbon atoms in the nuclei are linked to one another by a single bond.

The members of the paraffine series embrace gases, liquids, and solids. The latter form a mixture called paraffine. Paraffines are tasteless, inodorous, and unattacked in the cold by the strongest acids.

Petroleum, or coal-oil, contains many of the members of the gaseous and solid paraffine series, dissolved in the liquid paraffines.

Methane, or marsh-gas, is an inflammable gas derived from the decomposition of vegetable matter. It is obtained artificially by the action of heat on a mixture of sodium acetate and caustic alkali.

Methane, ethane, and propane are all colorless and inflammable gaseous hydrocarbons or paraffines.

Cymogene and rhigolene are very volatile liquids, obtained by condensing the more volatile products of the distillation of crude petroleum. They are employed for the artificial production of cold.

Gasoline, naphtha, and benzine are liquids obtained by the condensation of the less volatile products. They are employed for forming a cheap illuminating gas, by mixing their vapors with air. They are also used for cheap solvents, and as a substitute for turpentine.

The solid paraffines may be obtained from coal-oil by the action of nitric acid.

A solution of several liquids having different boiling-points may be separated into its constituent liquids by fractional distillation.

The paraffines, being saturated compounds, can only form new compounds by substitution or replacement; they may have one or several of their hydrogen atoms replaced, and so may form an immense variety of compounds.

The alcohols are formed by the combination of the radicals methyl, ethyl, propyl, butyl, amyl, etc., called the alcohol radicals, with hydroxyl.

Methyl alcohol, or wood-spirit, is formed by submitting wood to dry distillation. It is a colorless, mobile liquid, and is inflammable. It possesses considerable solvent powers.

Ethylic alcohol, or ordinary alcohol, is obtained by the fermentation of glucose, or substances readily transformed into glucose.

Pure alcohol is a mobile, colorless liquid, having a peculiar vinous odor. It is inflammable and volatile, and is used in the arts for its solvent powers, and in medicine as a stimulant.

In vinous fermentation, the sugar in the juice of the grape is converted into alcohol and carbonic acid by the action of a ferment obtained from the vegetable albumen of the grape.

Beer is a fermented liquor obtained from *malt*, or artificially germinated grain. The moistened grain is spread in heaps to sprout, during which a part of its starch is converted into glucose by the action of a peculiar ferment called *diastase*.

Yeast is a peculiar, fungus-like organism that collects on the surface of beer during its fermentation. Added to the dough of bread, it converts part of the sugar of the flour into alcohol and carbonic acid gas, the latter substance distending the dough and causing it to rise.

Ethers may be regarded as oxidized alcohol radicals. They are formed by the union of two alcohol radicals by a single oxygen atom. In the simple ethers the two alcohol radicals are both of the same kind; in the mixed ethers the two alcohol radicals are of different kinds.

Ethers are obtained by the action of sulphuric acid on the various alcohols.

Methylic ether, $CH_3.O—CH_3$, is a gas at ordinary temperatures.

Ethylic ether, $C_2H_5—O—C_2H_5$, or common ether, is obtained by the action of sulphuric acid on ordinary alcohol. It is a very mobile, colorless liquid, having a peculiar and penetrating odor. It is inflammable in air.

Common ether is largely employed for its solvent powers to dissolve fats, oils, gums, resins, and many other substances.

Common ether evaporates so rapidly that it is extensively employed to produce low temperatures. It is also employed as an anæsthetic.

The alcohol radicals combine with acid radicals, forming a class of salts called the compound ethers.

The compound radical —HS combines with the alcohol radicals, and forms a class of bodies called mercaptans, or thio-alcohols.

Ethyl mercaptan is a colorless, mobile liquid, possessing a very fetid odor.

There is also a class of salts resembling the ethers, in which two alcohol radicals are linked together by a sulphur atom instead of by an oxygen atom, as $C_2H_5—S—C_2H_5$, or ethyl sulphide.

The alcohol radicals may combine with nitrogen by replacing one, two, or three of the hydrogen atoms in ammonia, NH_3, thus forming primary, secondary, and tertiary amines.

The alcohol radicals may combine with phosphorus by replacing one, two, or three of the hydrogen atoms in phosphoretted hydrogen, PH_3, thus forming primary, secondary, and tertiary phosgenes. These substances are spontaneously inflammable.

The alcohol radicals may combine with arsenic by replacing the three atoms of hydrogen in arseniuretted hydrogen, AsH_3, thus forming tertiary arsines.

When arsenic combines with two alcohol radicals it forms a compound radical, two of which uniting form a very poisonous substance called cacodyl, which possesses a fearful smell.

QUESTIONS FOR REVIEW.

How is the radical cyanogen derived? How may potassium cyanide be produced?

By what means may gaseous cyanogen be obtained? What are its properties? Write its graphic formula.

What is the graphic formula for hydrocyanic acid? What is its common name? How may it be obtained? What are its properties?

How may the metallic cyanides be prepared? Name some of these cyanides, and write their formulæ.

Write the graphic formula showing the origin of the radical ferrocyanogen.

How is potassium ferrocyanide obtained? Write its formula. What are its properties? For what purposes is it employed?

How is Prussian blue prepared? How may a blue ink be prepared?

How is potassium ferricyanide made? What is its formula? What are its properties? For what is it used?

How is sodium nitroferrocyanide made? What is its formula? For what is it used?

Name some of the compounds of cyanogen with the haloids. Describe the properties of the liquid and the solid cyanogen chloride.

What is the derivation of cyanic acid? Name some of the cyanates.

How is potassium sulphocyanate obtained? What other name is sometimes given to it? What are its properties?

Name some of the derivatives of the radical carbonyl. What is the composition of urea? What is the source of the urea in the urine of animals? What is the composition of the compound ureas?

Write the names and formulæ of the homologous series of the paraffines, or the marsh-gas series.

Give a general description of these bodies.

In what common substance are most of them found?

Describe the properties of methane. How is this gas produced artificially? Where is it produced naturally? Is it poisonous?

Describe the properties of ethane and propane.

Describe the general properties of petroleum, or coal-oil. Name its principal locality.

What are cymogene and rhigolene? How are they obtained? For what are they used?

How are gasoline, naphtha, and benzine obtained? For what are they used?

What is the legal test for commercial petroleum when employed as an illuminant?

Describe the general process of fractional distillation. Describe the apparatus employed.

In what manner only can the paraffines form new compounds? Why?

How are the alcohols formed? What is meant by the alcohol radicals? Write the names and formulæ for the various alcohols.

How is methylic alcohol obtained? What is its common name? What are its properties? For what purposes is it employed?

How is ethylic, or ordinary alcohol obtained? Describe its properties. Name some of the purposes for which it is employed.

What are tinctures? How is absolute alcohol prepared?

Explain the cause of vinous fermentation.

Distinguish between dry wines and sweet wines. What are champagnes?

How is beer made? What is malt? What change occurs during the process of malting?

From what source is yeast obtained? In what manner does it cause bread to rise?

In what manner do the alcohol radicals produce ethers? Distinguish between simple and mixed ethers.

How are the ethers of the various alcohols obtained?

Describe the continuous process for the production of ethylic, or ordinary ether. Explain the part sulphuric acid plays in the process of etherification. Write the reactions that occur during this process.

Describe the properties of ethylic ether. For what different purposes is ether used?

Define an ethereal salt, or a compound ether. Name some of these salts. What is sweet spirits of nitre?

How may the alcohol radicals be caused to unite with sulphur? What are mercaptans?

Write the formula for ethyl sulphide. In what respects does this substance resemble an ether?

How may the alcohol radicals be caused to unite with nitrogen? What are these bodies called?

How may the alcohol radicals be caused to unite with phosphorus? What are these bodies called? Describe their properties.

How may the alcohol radicals be caused to unite with arsenic? What name is given to the bodies so formed?

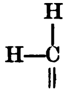
What are cacodyls? Describe their properties. Write the graphic formula for common cacodyl.

CHAPTER IV.

SINGLE-LINKED CARBON NUCLEI (Continued).

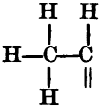
DERIVATIVES OF THE DYAD PARAFFINE RADICALS.

410. The Dyad Paraffine Radicals.—In the dyad paraffine radicals,



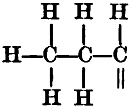
$$H-\overset{\displaystyle H}{\underset{\|}{C}}$$

CH_2



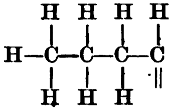
$$H-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-\overset{\displaystyle H}{\underset{\|}{C}}$$

C_2H_4



$$H-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-\overset{\displaystyle H}{\underset{\|}{C}}$$

C_3H_6

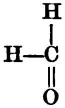


$$H-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-\overset{\displaystyle H}{\underset{\|}{C}}$$

C_4H_8

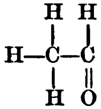
the two substitutions may occur on the same carbon atom, or on two separate carbon atoms.

When the two free bonds on a terminal carbon atom are closed by a single oxygen atom, derivatives called *aldehydes* are produced; thus,



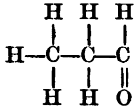
$$H-\overset{\displaystyle H}{\underset{\substack{\| \\ O}}{C}}$$

Methylic Aldehyde.



$$H-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-\overset{\displaystyle H}{\underset{\substack{\| \\ O}}{C}}$$

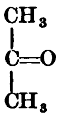
Ethylic Aldehyde.



$$H-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-\overset{\displaystyle H}{\underset{\displaystyle H}{C}}-\overset{\displaystyle H}{\underset{\substack{\| \\ O}}{C}}$$

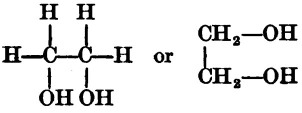
Propylic Aldehyde.

When both substitutions take place on an intermediate carbon atom that is united to the carbon atoms of alcohol radicals, bodies called *ketones* are produced. These bodies are formed by the oxidation of the secondary alcohols; thus,



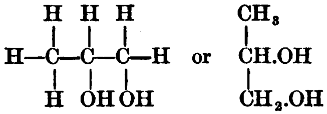
$$\begin{array}{l} CH_3 \\ | \\ C=O \\ | \\ CH_3 \end{array} = \text{Ketone, or Acetone.}$$

When each of the free bonds is closed by a hydroxyl radical, a class of bodies called *glycols*, or *diacid alcohols*, are produced; thus,



$$\begin{array}{c} \mathrm{H}\quad\mathrm{H} \\ | \quad\; | \\ \mathrm{H{-}C{-}C{-}H} \\ | \quad\; | \\ \mathrm{OH}\;\mathrm{OH} \end{array} \quad \text{or} \quad \begin{array}{l} \mathrm{CH_2{-}OH} \\ | \\ \mathrm{CH_2{-}OH} \end{array}$$

Ethylene Glycol.



$$\begin{array}{c} \mathrm{H}\quad\mathrm{H}\quad\mathrm{H} \\ | \quad\; | \quad\; | \\ \mathrm{H{-}C{-}C{-}C{-}H} \\ | \quad\; | \quad\; | \\ \mathrm{H}\quad\mathrm{OH}\,\mathrm{OH} \end{array} \quad \text{or} \quad \begin{array}{l} \mathrm{CH_3} \\ | \\ \mathrm{CH.OH} \\ | \\ \mathrm{CH_2.OH} \end{array}$$

Propylene Glycol.

411. The Aldehydes—The aldehydes are oxides of the dyad paraffine radicals. They are generally produced by the oxidation of the primary alcohols; thus,

$$\begin{array}{ccccccccc} C_2H_5,OH & + & O & = & H_2O & + & C_2H_4O \\ \text{Ethyl Alcohol} & + & \text{Oxygen} & = & \text{Water} & + & \text{Aldehyde.} \end{array}$$

The single oxygen atom removes two of the hydrogen atoms in the alcohol, and forms, with them, one molecule of water. The name aldehyde is a contraction for the Latin phrase *alcohol dehydrogenatum*, and means dehydrogenated alcohol.

It will be noticed that aldehyde contains one atom of oxygen less than does acetic acid. Aldehyde is very apt to be oxidized and converted into acetic acid. The peculiar smell noticeable in the breath of habitual hard drinkers is due to the presence of aldehyde. We will briefly describe a few of the more important of the aldehydes.

Methylic aldehyde, CH_2O, or methylic alcohol, CH_4O less H_2, is obtained by the oxidation of methylic alcohol, by causing a stream of air loaded with methyl alcohol vapor to impinge against a red hot platinum spiral. The heat evolved by the oxidation of the alcohol vapor maintains the wire at the proper temperature.

Methylic aldehyde may also be obtained from formic acid by removing one of its oxygen atoms. It is, therefore, sometimes called *formic aldehyde*.

Methylic aldehyde has not yet been obtained pure. It is only known as a vapor, or as an aqueous solution.

Ethylic aldehyde, C_2H_4O, or simply *aldehyde*, is readily obtained by the action of potassium bichromate and sulphuric acid on ordinary alcohol. A violent reaction ensues, and the aldehyde vapors are condensed in receivers surrounded by freezing mixtures.

Ethylic aldehyde is sometimes obtained from acetic acid, and is therefore called *acetic aldehyde.*

Ethylic aldehyde is a very mobile, colorless liquid, whose specific gravity is 0.801. It possesses a peculiar ethereal odor, which, when inhaled, produces a feeling of tightness in the chest. It rapidly evaporates on exposure to the air, with marked lowering of the temperature. It precipitates metallic silver from its ammoniacal solutions, and readily dissolves sulphur, phosphorus, and iodine. It is inflammable in air with a blue flame.

Trichloraldehyde, C_2Cl_3OH, or *Chloral*, is a very important substance extensively employed in medicine as a hypnotic (a producer of sleep), and as an anodyne (that which deadens pain).

Chloral is produced by the prolonged action of chlorine on ordinary alcohol. It is a colorless, mobile, oily liquid, possessing a peculiar and penetrating odor. It possesses but little taste, and is readily soluble in water, alcohol, and ether. When kept for some time, even in tightly-stoppered bottles, it becomes converted into a white solid that is almost entirely insoluble in water, alcohol, or ether. This change is also produced by contact with strong sulphuric acid.

Acrolein, C_3H_4O, or *acrylic aldehyde*, is formed by the destructive distillation of fats or glycerine.

Acrolein has powerful reducing properties, reducing silver oxide. Nascent hydrogen converts acrolein into propionic acid.

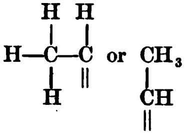
Butylic aldehyde, C_4H_8O, or butyric aldehyde, is a strongly refracting liquid, with a peculiar penetrating odor.

Œnanthic aldehyde, $C_7H_{14}O$, is produced from castor-oil. It is an oily liquid with an extremely disagreeable smell.

Palmitic aldehyde and *stearic aldehydes* are solid bodies, and crystallize in leafy crystals.

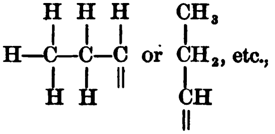
The aldehydes are intermediate between the alcohols and the fatty acids, and may be converted into either of these substances. As a rule, the aldehydes readily oxidize on exposure to the air, and become converted into their corresponding fatty acids.

412. Derivatives of the Aldehyde Radicals.—We may regard



$$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{\|}{C}} \text{ or } \overset{CH_3}{\underset{\underset{\|}{CH}}{|}}$$

Ethylidene.



$$H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{\|}{C}} \text{ or } \overset{CH_3}{\underset{\underset{\underset{\|}{CH}}{|}}{\overset{|}{CH_2}}}\text{, etc.,}$$

Propylidene.

as the *aldehyde radicals.*

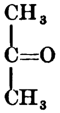
The aldehyde radicals form a number of derivatives by having their free bonds saturated by different elements or compound radicals. Thus ethylidene, $CH_3-\underset{\|}{CH}$, forms with chlorine, *ethylidene dichloride,* CH_3-CHCl_2, a colorless liquid having an odor like chloroform. With bromine it forms *ethylidene dibromide,* $CH_3-CH.Br_2$, a yellowish, oily liquid.

413. Ethereal Compounds of the Aldehyde Radicals.—Just as the ethers may be regarded as composed of two alcohol radicals, united by a single oxygen atom, so also the aldehyde radicals may be similarly linked to the monad alcohol radicals; thus *ethylidene dimethylate,* $CH_3.CH(O.CH_3)_2$, is a liquid prepared by the oxidation of methylic and ethylic alcohols. It occurs in crude wood spirit.

Ethylidene ethylate, or *acetal,* $CH_3.CH.(O.C_2H_5)_2$, is prepared by oxidizing ethylic alcohol. It is a mobile, colorless liquid.

Numerous other derivatives of the aldehyde radicals exist.

414. The Ketones or Acetones.—These bodies result when two of the hydrogen atoms, linked to a carbon atom that is united to two carbon atoms of separate alcohol radicals in a paraffine, are replaced by an atom of oxygen. The lowest originator of such a series must evidently contain at least three carbon atoms, as propane, since the carbon atom in which the substitution occurs is intermediate in position to two other carbon atoms; thus:



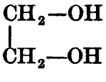
$$\begin{array}{l} CH_3 \\ | \\ C{=}O \\ | \\ CH_3 \end{array} = \text{Acetone, a body isomeric with Propionic Aldehyde.}$$

415. Acetone or Dimethyl Ketone, C_3H_6O, is most readily prepared by the dry distillation of calcium acetate. The condensed vapors yield *acetone.*

Acetone is a colorless, mobile liquid, possessing a peculiar but agreeable ethereal odor. Its specific gravity is .814. It mixes in all proportions with alcohol, ether, and water, and, like alcohol, acts as a solvent for fats, etc. Its vapor is inflammable, burning in the air with a luminous flame.

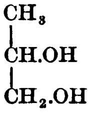
Many other ketones exist; thus, *methyl-nonyl-ketone,* $CH_3.CO.C_9H_{19}$, which is the main ingredient in *oil of rue.*

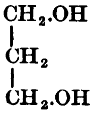
416. The Glycols or Diacid Alcohols.—These bodies result when the dyad radicals have their free bonds closed by hydroxyl radicals. The lowest compound of the group must contain two carbon atoms; thus, $C_2H_4(OH)_2$, or,



$$\begin{array}{l} CH_2{-}OH \\ | \\ CH_2{-}OH \end{array} = \text{Ethylene glycol.}$$

The higher *glycols* present numerous isomeric modifications; thus, $C_3H_6(OH)_2$, or,





$$\begin{array}{l} CH_3 \\ | \\ CH.OH \\ | \\ CH_2.OH \end{array} = \begin{array}{c}\text{Propylene}\\ \text{glycol,}\end{array} \quad \text{and} \quad \begin{array}{l} CH_2.OH \\ | \\ CH_2 \\ | \\ CH_2.OH \end{array} = \begin{array}{c}\text{Trimethene}\\ \text{glycol.}\end{array}$$

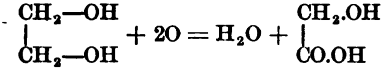
The glycols are, for the most part, syrupy liquids. They produce diatomic acids by oxidation.

The following are some of the glycols, viz.:

Ethylene glycol, or glycol $= C_2H_6O_2$.
Propylene glycol $= C_3H_8O_2$.
Butylene glycol $= C_4H_{10}O_2$.
Amylene glycol $= C_5H_{12}O_2$.
Hexylene glycol $= C_6H_{14}O_2$.

417. Glycol, or Ethylene Dihydrate, $C_2H_4(OH)_2$, is a syrupy, colorless liquid, having a sweet, alcoholic taste, but no odor. It is readily dissolved by alcohol and water, with which it mixes in all proportions. When glycol is heated with nitric acid, red fumes are disengaged, and crystals of oxalic acid are deposited on cooling.

Glycol, when oxidized by two atoms of oxygen, yields *glycolic acid,* which corresponds to the acetic acid of ordinary alcohol, thus:

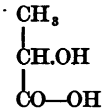


$$\begin{array}{l} CH_2{-}OH \\ | \\ CH_2{-}OH \end{array} + 2O = H_2O + \begin{array}{l} CH_2.OH \\ | \\ CO.OH \end{array}$$

Glycol. Glycolic Acid.

Many other glycols exist, for example, *Propylene glycol,* $C_3H_6(OH)_2$, a colorless, syrupy liquid, possessing a sweet taste.

418. Lactic Acid, $C_3H_6O_3$, an acid discovered by Scheele in sour milk, is homologous with glycolic acid. Its composition is believed to be as follows, viz.:



$$\begin{array}{l} CH_3 \\ | \\ CH.OH \\ | \\ CO{-}OH \end{array}$$

Lactic Acid.

that is, it is both an alcohol and an acid.

Lactic acid is most conveniently prepared by exposing a mixture of glucose, sour milk, old cheese, lime and water for a week to a temperature of about 95° F. By this means the acid is obtained in the form of calcium lactate. The acid is produced by means of a species of fermentation known technically as the *lactic fermentation.* Lactic acid exists in sauerkraut.

Lactic acid is a colorless, syrupy liquid, whose specific gravity is 1.215. It has an intensely sour taste, and is freely soluble in water, alcohol, and ether.

Lactic acid forms various salts, called lactates.

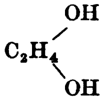
419. Ethers of the Glycols.—When alcohol or acid radicals are substituted for the hydrogen in the hydroxyl groups, OH, ethers of the glycols result, that is, radicals partially or entirely linked by oxygen, thus:

$$C_2H_4\left\{\begin{matrix}O—C_2H_5\\OH\end{matrix}\right. = \text{Monethylic glycol.}$$

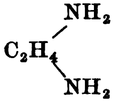
$$C_2H_4\left\{\begin{matrix}O—C_2H_5\\O—C_2H_5\end{matrix}\right. = \text{Diethylic glycol.}$$

$$C_2H_4\left\{\begin{matrix}O—C_2H_3O\\O—C_2H_3O\end{matrix}\right. = \text{Glycol diacetate.}$$

So also *diatomic ammonias* or *diamines* may result from the replacement of the hydroxyl group by the compound radical amine, NH_2, thus:



Glycol.



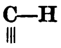
Ethylene diamine.

CHAPTER V.

SINGLE-LINKED CARBON NUCLEI (Continued).

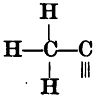
THE TRIVALENT PARAFFINE RADICALS.

420. Derivatives of the Trivalent Paraffine Radicals.—The trivalent paraffine radicals,



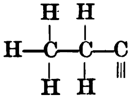
$\underset{\equiv}{\mathrm{C}}\mathrm{-H}$

CH



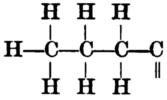
$\mathrm{H-\overset{H}{\underset{H}{C}}-\underset{\equiv}{C}}$

C_2H_3



$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\underset{\equiv}{C}}$

C_3H_5



$\mathrm{H-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\overset{H}{\underset{H}{C}}-\underset{=}{C}}$

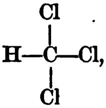
C_4H_7

etc., form a variety of triple substitution compounds, which may be divided into three classes, viz.:

1st. All three substitutions occur on the same carbon atom, as in chloroform and the fatty acids.

2d. Two substitutions may occur on a terminal carbon atom, as in the mono-substituted aldehyde radicals, or two substitutions may occur on an intermediate carbon atom, and the remaining on any other carbon atom, as in the mono-substituted ketone radicals.

3d. The substitution occurs on three different carbon atoms, as in the trivalent alcohol radicals, such as glyceryl or allyl.

421. Formyl Trichloride,  $\mathrm{H-\overset{Cl}{\underset{Cl}{C}}-Cl}$, **or Chloroform,** is obtained by distilling alcohol mixed with half its weight of chloride of lime, or bleaching powder. The distilled liquid separates into two layers, the lower of which consists principally of chloroform. This is washed with water and distilled over sulphuric acid.

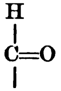
Chloroform is a mobile, colorless liquid, possessing a burning taste and an agreeable ethereal smell. Its density is 1.52, and its boiling-point is 142° F. It does not mix with water, but is soluble in ether and alcohol, and dissolves phosphorus, bromine, iodine, and numerous organic substances, such as fats, resins, and many of the alkaloids.

Chloroform is often employed as an anæsthetic, but must then be pure. Its use for this purpose is not considered as safe as that of ether.

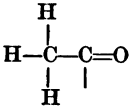
Chloroform is converted into carbon tetrachloride by boiling it with chlorine in the presence of sunlight.

Iodoform, CHI_3 (solid), and *bromoform*, $CHBr_3$ (liquid), resemble chloroform in many of their chemical properties.

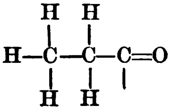
422. The Fatty Acids.—When the trivalent paraffine radicals, CH, C_2H_3, C_3H_5, C_4H_7, etc., have two of the bonds of the carbon atom saturated with an oxygen atom, they form a series of univalent acid radicals, called the *acidoxyls*, thus:


$\overset{H}{\underset{|}{C}}{=}O$

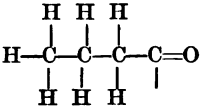
CHO


$H{-}\overset{H}{\underset{H}{C}}{-}\underset{|}{C}{=}O$

C_2H_3O

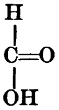

$H{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\underset{|}{C}{=}O$

C_3H_5O


$H{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\underset{|}{C}{=}O$

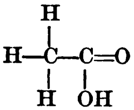
C_4H_7O, etc.

The fatty acids are derived from these radicals by having their free bond saturated with hydroxyl, thus:


$\overset{H}{\underset{OH}{C}}{=}O$

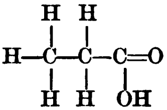
Formic Acid.

CH_2O_2


$H{-}\overset{H}{\underset{H}{C}}{-}\underset{OH}{C}{=}O$

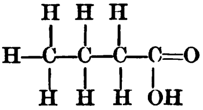
Acetic Acid.

$C_2H_4O_2$


$H{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\underset{OH}{C}{=}O$

Propionic Acid.

$C_3H_6O_2$


$H{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\overset{H}{\underset{H}{C}}{-}\underset{OH}{C}{=}O$

Butyric Acid.

$C_4H_8O_2$

The following list contains the principal of these acids, together with their boiling-points, viz.:

			Boiling-point.
Formic	Acid	$= CH_2O_2$ . .	99° C.
Acetic	"	$= C_2H_4O_2$ . .	119° C.
Propionic	"	$= C_3H_6O_2$ . .	141° C.

			Boiling-point.
Butyric	Acid	$= C_4H_8O_2$ . .	163° C.
Valeric	"	$= C_5H_{10}O_2$ . .	185° C.
Caproic	"	$= C_6H_{12}O_2$ . .	205° C.
Œnanthylic	"	$= C_7H_{14}O_2$ . .	223°.5 C.
Caprylic	"	$= C_8H_{16}O_2$ . .	236° C.
Pelargonic	"	$= C_9H_{18}O_2$ . .	253°.5 C.

			Boiling-point under diminished pressure.
Capric	"	$= C_{10}H_{20}O_2$ . .	269° C.
Undecylic	"	$= C_{11}H_{22}O_2$ . .	212°.5 C.
Lauric	"	$= C_{12}H_{24}O_2$ . .	225°.5 C.
Tridecylic	"	$= C_{13}H_{26}O_2$ . .	236° C.
Myristic	"	$= C_{14}H_{28}O_2$ . .	248° C.
Pentadecylic	"	$= C_{15}H_{30}O_2$ . .	257° C.
Palmitic	"	$= C_{16}H_{32}O_2$ . .	268°.5 C.
Margaric	"	$= C_{17}H_{34}O_2$ . .	277° C.
Stearic	"	$= C_{18}H_{36}O_2$ . .	287° C.
Nondecatylic	"	$= C_{19}H_{38}O_2$	
Arachidic	"	$= C_{20}H_{40}O_2$	
Medullic	"	$= C_{21}H_{42}O_2$	
Behenic	"	$= C_{22}H_{44}O_2$	
Lignoceric	"	$= C_{24}H_{48}O_2$	
Hyaenasic	"	$= C_{25}H_{50}O_2$	
Cerotic	"	$= C_{27}H_{54}O_2$	
Melissic	"	$= C_{30}H_{60}O_2$	

The fatty acids may be prepared from the primary alcohols by oxidation, or from the next lower alcohols by an increase of the carbon nucleus.

423. Formic Acid, HCO.OH, occurs in nature in the bodies of ants, from which its name is derived. It also occurs in the stinging-nettle, in certain caterpillars, and in pine needles. These bodies all yield the acid on being distilled with water.

Formic acid is obtained artificially by heating oxalic acid, thus:

$$C_2H_2O_4 + \text{Heat} = CO_2 + CH_2O_2$$

Oxalic Acid + Heat = Carbon Dioxide + Formic Acid.

Formic acid is a mobile, colorless liquid, whose specific gravity = 1.23. It acts powerfully on the skin, blistering it and leaving a painful wound. It has a penetrating acid odor and a sharp acid taste.

Formic acid acts as a powerful antiseptic, preventing both putrefaction and fermentation. It acts as a powerful reducing agent for the oxides of silver, mercury, gold, etc.

Formic acid yields a class of crystalline salts called the *formates*, that are all soluble in water.

424. Acetic Acid, $C_2H_4O_2$, is the acid in vinegar. It can be obtained artificially in a variety of ways, but is generally prepared by the oxidation of alcohol, or, when required in large quantities for various uses in the arts, by the destructive distillation of wood.

Crude sodium acetate is obtained by distilling wood in closed iron vessels, and condensing the products by means of a worm cooled by water. The combustible gases evolved are burned under the iron retorts. The crude acetic acid thus produced is neutralized by lime, and the calcium acetate so formed converted, by the addition of sodium sulphate to the solution, into sodium acetate, which is suitably purified and crystallized. Pure acetic acid may be readily obtained from this salt by distilling it with strong sulphuric acid.

Acetic acid is a colorless, mobile liquid, having, at the melting-point of ice, a specific gravity of 1.08. It is strongly acid and corrosive, and possesses a pungent taste and smell. On being cooled it crystallizes in transparent, hygroscopic tables, sometimes called glacial acetic acid.

Acetic acid possesses great solvent powers. In a diluted form it is largely employed in calico printing. Ordinary vinegar is merely a diluted aqueous solution of acetic acid.

425. The Manufacture of Vinegar.—Vinegar results when diluted alcohol is mixed with a little yeast, or almost any putrescible nitrogeneous matter, and allowed to ferment. This species of fermentation is called *acetic fermentation*, in order to distinguish it from the *vinous fermentation* already described.

The ferment producing the change is called *mother of vinegar,* and appears on the surface of the liquid as a mould. It is an organized product, and acts by absorbing oxygen from the air, and yielding it subsequently to the alcohol. This ferment is always present in crude vinegar, and on beginning the process, some vinegar is first added to the sugar or alcohol, so as to readily start the fermentation.

In *the quick vinegar process,* diluted alcohol is exposed to the air while slowly trickling through a barrel partially filled with shavings. Some crude vinegar is first poured in to start the fermentation. The shavings only partially fill the middle of the barrel, being contained between a double perforated top and bottom. The dilute alcohol is poured in above, and slowly trickles on to the shavings, and thence to the empty space at the bottom of the barrel. Air is admitted to the barrel by holes, *a a,* at the side, and escapes from it through the tubes A A′. In order to convert all the alcohol into acetic acid, the same liquid is passed twice through the barrel, Fig. 139.

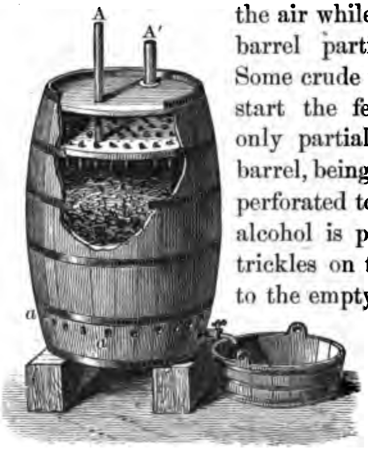


Fig. 139.—The Quick Vinegar Process.

426. Acetates.—Acetic acid forms a variety of important salts called the acetates. These salts contain one or two molecules of acetic acid, according to whether the metal replaces one or two atoms of basic hydrogen in the acid. The acetates are soluble in water.

Potassium acetate, $KC_2H_3O_2$, is formed by the action of potassium carbonate on acetic acid. It crystallizes in deliquescent laminæ.

Sodium acetate, $NaC_2H_3O_2$, is obtained as already described by the distillation of wood.

Ammonium acetate, $NH_4C_2H_3O_2$, is formed by neutralizing acetic acid with ammonia. It is used in medicine as *spirit of Mindererus.*

Lead diacetate, $Pb(C_2H_3O_2)_2+3H_2O$, *neutral lead acetate,* or *sugar of lead,* is obtained by dissolving litharge in distilled vinegar. It crystallizes in transparent oblique rhombic prisms, that soon effloresce and whiten. It has a sweetish, metallic taste, and is quite poisonous.

The solution of neutral lead acetate dissolves oxide of lead, and forms a variety of basic acetates. *Neutral copper acetate,* $Cu(C_2H_3O_2)_2+H_2O$, is obtained when sodium acetate is mixed with cupric sulphate.

The di-basic copper acetate, $Cu(C_2H_3O_2)_2+CuO+6H_2O$, or verdigris, is the green deposit that forms on copper and brass exposed to acetic acid or vinegar vapors. It is formed on a large scale by exposing sheets of copper covered with the pulp of grapes to the air. It forms the basis of a green paint.

Acetic anhydride, $C_4H_6O_3=(C_2H_3O)_2O$, or *anhydrous acetic acid,* may be obtained by acting on acetyl chloride by potassium acetate. It is a heavy oil, which gradually dissolves in water and becomes changed into acetic acid; thus,

$$\underset{\text{Acetic Anhydride}}{(C_2H_3O)_2O} + \underset{\text{Water}}{H_2O} = \underset{\text{Acetic Acid.}}{2C_2H_3O(OH)}$$

Acetamide, $C_2H_3ONH_2$, is obtained by heating ethyl acetate in a sealed tube with aqueous ammonia to the temperature of boiling water.

Acetamide is a solid, crystalline substance, possessing in a remarkable degree the odor of mice.

427. Propionic Acid, $C_3H_6O_2$, somewhat resembles acetic acid. It is a colorless, oily liquid, and derives its name from προτος, the first, and πιον, fat, being the first of the acids that possesses a fatty appearance. Its smell somewhat resembles acetic acid. It is produced along with the acetic acid during the distillation of wood. It may also be obtained in a variety of other ways.

428. Butyric Acid, $C_4H_8O_2$, occurs in rancid butter. It is a mobile, colorless liquid, having a very disagreeable odor and a strong, acid taste. Its specific gravity is 0.98. Like propionic acid, it mixes in all proportions with water, with which it forms an oily liquid. It may be prepared in a variety of ways, one of the most convenient of which is by allowing sugar to ferment when mixed with putrid cheese and chalk. It forms a variety of salts called the butyrates. Most of the metallic butyrates are soluble in water.

429. Valeric Acid, $C_5H_{10}O_2$, receives its name from the fact that it is obtained by distilling valerian root with water. It may also be obtained by the oxidation of amyl alcohol. It is a colorless acid liquid, having a peculiar and disagreeable odor. Its specific gravity is 0.94. The acid obtained from the distillation of the valerian root, and the zinc and ammonium valerates, are used in medicine.

430. Caproic Acid, $C_6H_{12}O_2$, is a colorless oil, having a specific gravity of 0.93. Its odor faintly resembles that of sweat. It may be prepared in a variety of ways, one of the most convenient of which is from cocoa-nut oil. *Leucine,* an animal product found in the liver, spleen, and various other organs, is a substitution compound of caproic acid, in which one of the hydrogen atoms is replaced by the radical NH_2, thus, $C_6H_{11}(NH_2)O_2$.

Œnanthylic acid, $C_7H_{14}O_2$, a colorless, oily liquid, whose specific gravity is 0.934, is obtained indirectly from castor-oil. Its odor resembles codfish.

431. Acids Richer in Carbon.—Nearly all the remaining acids of the series are obtained from the different fats, which are salts of the acid with glycerine. When *saponified,* or converted by alkalies into soaps, that is, into alkali salts, the glycerine separates. Soap dissolved in excess of water is generally decomposed into free alkali and the fatty acid. We will describe only some of these.

Caprylic acid, $C_8H_{16}O_2$, exists in butter, in cocoa-nut oil, and in various vegetable fats. Its odor resembles that of sweat. It crystallizes in needles or plates.

Pelargonic acid, $C_9H_{18}O_2$, is obtained from the geranium, and from *oil of rue.* It has an unpleasant smell. The bouquet, or aroma of certain wines, is due to the ether of this acid, which is produced during the fermentation.

Capric acid, $C_{10}H_{20}O_2$, exists in butter, cocoa-nut oil, and in various fats. It is a solid at ordinary temperature. Its odor strongly resembles the peculiar smell of goats.

Palmitic acid, $C_{16}H_{32}O_2$, exists in nearly all vegetable and animal fats, associated in the latter with stearic and oleic acids. It exists in olive oil, associated almost solely with oleic acid, and is readily obtained from olive oil by saponifying it with soda. Palmitic acid is colorless and odorous, and crystallizes in needles.

Margaric acid, $C_{17}H_{34}O_2$, resembles palmitic acid.

Stearic acid, $C_{18}H_{36}O_2$, exists especially in the more solid of the animal fats, along with palmitic acid, with which it is largely produced for the manufacture of *stearine candles.* For this purpose the fat is heated under pressure in water containing a little sulphuric acid, by which the glycerine is separated from the fatty acids. These latter solidify on cooling, and the solid acids are separated from the more liquid products by a hydraulic press.

Cerotic acid, $C_{27}H_{54}O_2$, exists in beeswax, of which it forms the chief constituent. It may be obtained from beeswax by the action of boiling ether.

432. The Ethereal Salts, or Compound Ethers.—When the fatty acids are mixed with the alcohols and heated, they are converted into compound ethers. These ethers are true substitution compounds, in which the hydrogen of the acid is replaced by the alcohol radical; thus,

$$\underset{\text{Alcohol}}{C_2H_5OH} + \underset{\text{Acetic Acid}}{C_2H_3O,OH} = \underset{\text{Ethyl Acetate}}{C_2H_5O(C_2H_3O)} + \underset{\text{Water.}}{H_2O}$$

All the compound ethers, except those of high molecular constitution, are liquids that are characterized by agreeable odors. The peculiar flavors or taste of fruits is generally due to these compounds, which occur naturally in the fruit. The artificial ethers are manufactured in large quantities for use in the artificial flavors used in confectionery. Some solid crystalline compound ethers are found in different kinds of wax. We will describe some of the more important volatile liquid compound ethers.

Methyl acetate, $CH_3,C_2H_3O_2$, is obtained by distilling a mixture of wood spirit, glacial acetic acid, and sulphuric acid. It is a mobile liquid with a fragrant, refreshing odor.

Ethyl acetate, $C_2H_5,C_2H_3O_2$, is obtained by distilling a mixture of potassium acetate, alcohol, and sulphuric acid. It is a mobile, fragrant liquid, possessing a pleasant smell and an agreeable burning taste. It is used in medicine and for the adulteration of wines and liquors.

Amyl acetate, $C_5H_{11},C_2H_3O_2$, is prepared by distilling a mixture of amyl alcohol, potassium acetate, and sulphuric acid. Its odor and flavor strongly resemble Jargonelle pear; it is, therefore, largely employed in confectionery and for flavoring liquors.

Ethyl butyrate, $C_2H_5,C_4H_7O_2$, is obtained by distilling a mixture of alcohol, and butyric, and sulphuric acids. It is a colorless liquid, possessing the odor of pineapples, and is largely used in confectionery and for cheap perfumery.

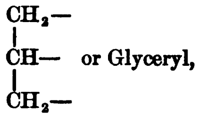
Amyl valerate, $C_5H_{11},C_5H_9O_2$, is obtained by warming amyl alcohol with valeric acid and sulphuric acid. It is a mobile, colorless liquid, having the agreeable odor of apples. It is used in confectionery.

Cetylic palmitate, $C_{16}H_{33},C_{16}H_{31}O_2$, constitutes the greater bulk of spermaceti, a substance obtained from the oil of certain whales. It is a solid at ordinary temperature.

Melissylic palmitate, $C_{30}H_{61},C_{16}H_{31}O_2$, is one of the constituents of beeswax. It is a solid substance.

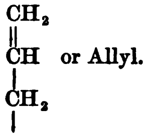
The derivatives of the monosubstituted aldehyde and ketone radicals are comparatively unimportant.

433. Derivatives of the Trivalent Alcohol Radicals.—The trivalent radical C_3H_5, or



$$\begin{array}{l} CH_2- \\ | \\ CH- \quad \text{or Glyceryl,} \\ | \\ CH_2- \end{array}$$

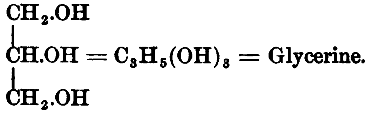
may become monivalent by the double combination of two of its carbon atoms; thus,



$$\begin{array}{l} CH_2 \\ \| \\ CH \quad \text{or Allyl.} \\ | \\ CH_2 \\ | \end{array}$$

Allyl belongs to the group of unsaturated, double-linked carbon nuclei, and will be treated thereunder. The most important compound of the trivalent radical is glycerine.

434. Glycerine.—Glycerine is produced by the union of three hydroxyl groups with the open bonds of the trivalent radical *glyceryl;* thus,



$$\begin{array}{l} CH_2.OH \\ | \\ CH.OH = C_3H_5(OH)_3 = \text{Glycerine.} \\ | \\ CH_2.OH \end{array}$$

Glycerine is, therefore, a triatomic alcohol.

The animal and vegetable fats are, as we have already seen, compounds of glycerine with the fatty acids. When these fats are decomposed by boiling with powerful basic hydrates, compounds called soaps are formed with the acids, and the glycerine is separated.

Nearly all the glycerine of commerce was formerly obtained as a by-product in the manufacture of *lead plaster*. In order to obtain this plaster, olive or other suitable oil is heated with lead oxide and water. This produces a lead soap and free glycerine. The latter is purified by treatment with hydrogen sulphide, digested with animal charcoal, and filtered.

Glycerine is now produced in large quantities and in a very pure condition by the decomposition of fatty substances by superheated steam, a process used in the preparation of stearic acid for the manufacture of candles. The stearic acid and the glycerine are carried over by the steam in a mixed condition, but afterwards separate into two layers.

Pure glycerine is a colorless, viscid liquid, whose specific gravity is 1.27. It has a very sweet taste and mixes with water in all proportions.

435. The Manufacture of Soap.—Soaps are mixtures of potassium, or sodium salts, of such fatty acids as stearic, palmitic, oleic, etc., and are obtained by saponifying natural fats by caustic alkali.

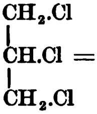
Soaps may be divided into two classes, viz., hard soaps and soft soaps. Hard soaps are mainly sodium salts of palmitic, oleic, and stearic acids. Soft soaps are potassium salts of the fatty acids.

Soap is soluble in water, and a concentrated aqueous, hot solution solidifies on cooling. It is, however, insoluble in brines; consequently, if common salt be added to a solution of soap, the soap separates as an oily liquid, which becomes solid when cooled. This solid is then boiled with water or a weak alkali, again separated by salt, and reboiled with a soda solution, and allowed to settle, when pure soap is produced.

Soaps are decomposed by a large quantity of water into free alkali and insoluble fatty acid. Their cleansing property is owing to the free alkali removing the greasy dirt, and the fatty acid producing a lather which carries off the grease and dirt. The free alkali also dissolves a very thin layer of the skin, and thus rapidly removes the dirt.

Various grades of soap are produced, depending on the character and purity of the fats and oils employed. Tallow, olive oil, and palm oil form the best soaps. A very cheap soap is made from common rosin. A silicate soap, much used for scouring metal and stone surfaces, is made by stirring sand into the warm soap before allowing it to solidify.

436. Derivatives of Glycerine.—Any or all the hydroxyl groups in glycerine may be replaced by the halogens, or by compound radicals, thus giving rise to a number of substitution compounds. For example, *glyceryl trichloride*, or *trichlorhydrin*.



$$\begin{array}{l} CH_2.Cl \\ | \\ CH.Cl = \text{Glyceryl trichloride} \\ | \\ CH_2.Cl \end{array}$$

is a colorless liquid, resembling chloroform in odor. Its specific gravity = 1.47.

So, also, *tribromhydrin*, C_3H_5,Br_3, and *triiodohydrin*, and numerous other substances.

437. Trinitroglycerine, $C_3H_5,(O.NO_2)_3$, is one of the most important of the substitution compounds of glycerine.

Nitroglycerine is obtained by slowly pouring glycerine, drop by drop, into a mixture of fuming nitric and sulphuric acids, the heat that ensues being prevented from considerably raising the temperature by the use of freezing-mixtures. Drops of a yellowish oil are formed, which are *trinitroglycerine*. This substance is poisonous, has a sweetish taste, and when struck a blow, or rapidly heated, explodes with fearful violence. It is much employed as a blasting agent, either in a pure state or when mixed with fine sand. In this latter case, it forms the well-known *dynamite*.

438. Fats and Oils.—The compounds of glycerine with the fatty and other acids that occur naturally as vegetable and animal fats or oils, seldom exist as compounds of glycerine with any single fatty acid, but as mixtures of combinations of glycerine with various acids.

Drying oils are such as contain acids that are readily oxidized by exposure to the air. They are then rendered hard, being changed by oxidation into substances resembling resins. Linseed oil, hempseed oil, and castor oil are drying oils.

Two processes may be employed in order to extract fats from animal or vegetable tissues, viz.: by pressure, aided by heat, so as to burst the cells containing the fats; or by dissolving the fats by ether, carbon bisulphide, or naphtha. In this latter case, the fat is separated from the solution by the evaporation of the dissolving liquid.

439. Derivatives of the Higher Alcohol Radicals.—The higher alcohol radicals give rise to numerous derivative substances. We will describe but a few of them.

Oxalic acid, $C_2H_2O_4 = CO(OH)-CO(OH)$, is an important acid that exists in many plants as a potassium or calcium oxalate. It also sometimes occurs as calcium oxalate in the urine of animals.

Oxalic acid is prepared commercially by several processes. One of these consists in the action of caustic potash on sawdust or shavings of wood at a high heat, when potassium oxalate is formed.

Oxalic acid may also be obtained by the oxidizing action of nitric acid on an inferior quality of molasses.

Oxalic acid crystallizes in large transparent prisms, shown in Fig. 140. They contain two molecules of water of crystallization. On exposure to the air they lose this water and effloresce.

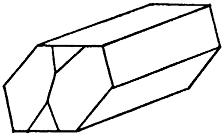


Fig. 140.—Oxalic Acid.

Oxalic acid is very poisonous. Its antidote is milk of lime, with which it forms an insoluble calcium acetate. Oxalic acid is employed for the removal of ink stains.

Oxalic acid forms a variety of oxalates, the most important of which is *potassium acid oxalate*, $KHC_2O_4+H_2O$, known commercially as salt of sorrel.

Oxalic acid has been obtained synthetically by passing carbon dioxide over metallic sodium mixed with dry quartz sand, heated to 662° F.

Malic acid, $C_4H_6O_5$, is the acid that imparts the sour taste to sour apples, quinces, gooseberries, and cranberries. It crystallizes in colorless needles, and is soluble in water, to which it imparts a sour taste.

Tartaric acid, $C_4H_6O_6$, is the acid of grapes. It derives its name from the *tartar*, or *argol* of wine-casks, from which it is largely derived. Argol is principally potassium acid tartrate, $C_4H_5O_6K$, which, converted into calcium tartrate and decomposed by H_2SO_4, yields colorless oblique rhombic prisms of tartaric acid, that are soluble in water, and have a very sour taste. Tartaric acid is dibasic.

Potassium acid tartrate, $C_4H_5O_6K$, or *cream of tartar*, is used in connection with $NaHCO_3$, as a baking-powder. When mixed with the sodium carbonate it drives off the carbonic acid which distends the dough.

Tartar emetic, or *antimonio-potassium tartrate*, $K(SbO)C_4H_6O_6$, is a very poisonous substance, that is used in small quantities in medicine as an emetic. It crystallizes in colorless rhombic octahedra.

Citric acid, $C_6H_8O_7$, is the acid of oranges, lemons, limes, etc. It has a very sour taste, and is used to make acid drinks. Citric acid crystallizes in colorless crystals derived from right-rhombic prisms. It is tribasic. The citrates are used in medicine.

Succinic acid, $C_4H_6O_4 = CO{-}OH{-}CH_2{-}CH_2{-}CO.OH$, was originally obtained from the distillation of amber, but is found among other products when such of the fatty acids as palmitic or stearic are oxidized by nitric acid.

Succinic acid occurs in large colorless crystals, that are soluble in water.

Uric acid, $C_5H_4N_4O_3$, may be obtained from certain urinary calculi; from the excreta of serpents, and from guano. It is a light, crystalline, whitish powder, that is insoluble in alcohol and ether.

When heated in small amount with nitric acid, it is dissolved with the evolution of nitrous fumes. The residue, gently evaporated to dryness, changes to a purple substance called *murexide* on the addition of a drop of ammonia. This is a characteristic test of uric acid.

Uric acid yields numerous derivative compounds.

◆

GROUP OF THE CARBOHYDRATES—SUGARS, STARCHES, AND GUMS.

440. Characteristics of the Group.—The group of the carbohydrates includes a great variety of compounds formed under the influence of life, mainly that of the vegetable world. Though none of the members of this group have been produced synthetically, yet enough of their composition is known to ally them to the polyatomic alcohols. They nearly all correspond to one or the other of the following formulæ, viz., $C_6H_{12}O_6$, $C_{12}H_{22}O_{11}$, or $C_6H_{10}O_5$. It will be observed that in all these cases the hydrogen and the oxygen are present in the proportion to form water. If, therefore, all the hydrogen and oxygen be driven out nothing but the carbon remains.

441. Glucose, $C_6H_{12}O_6$, is the most important of the sugars. It is very widely disseminated in the vegetable kingdom, and exists in all dried fruits and in honey.

Glucose may be obtained by the action of dilute sulphuric or hydrochloric acid on starch, and is obtained by this process in very large quantities. It is not readily crystallizable, but forms in masses resembling cauliflowers. It is not as sweet as cane-sugar, and not as soluble. It is largely used in confectionery, and in the preparation of syrups.

Glucose is soluble in alcohol. It acts as an aldehyde in reducing copper and silver salts when heated with their solutions.

442. Varieties of Glucose.—There are a number of different varieties of glucose; the following are among the more important, viz.:

Maltose, obtained by the action of diastase on starch. It is merely a physical modification of glucose.

Levulose, produced when cane-sugar is acted on by acids. It is a colorless, sweet, and uncrystallizable syrup.

443. Saccharose, $C_{12}H_{22}O_{11}$, or cane-sugar, is derived from the sugar-cane, sugar-beet, sorghum, and sugar-maple.

In extracting the sugar from the sugar-cane, the stalks are crushed between rollers, and the expressed juice heated to near its boiling-point. The clarified syrup is concentrated and allowed to crystallize, frequent stirring being employed to prevent the formation of large crystals. The product so obtained is called *raw sugar.* Before use it is subject to the process of refining, which consists essentially in dissolving the sugar in water, and mixing the solution with the albumen of eggs or blood, and heating to the boiling-point. The albumen coagulates, and mechanically separates the suspended impurities. The syrup is then decolorized by filtration through animal charcoal, and the clear syrup concentrated by boiling in *vacuum pans,* when the concentrated liquid is set apart to crystallize.

By long boiling, especially in the presence of dilute acid, the molecule of sugar becomes hydrated, and breaks up into two molecules, one of glucose and one of levulose. The sugar cannot then be recovered, as the solution is uncrystallizable. Such a mixture constitutes ordinary molasses.

444. Lactose, or Milk Sugar, $C_{12}H_{22}O_{11}+H_2O$, exists dissolved in milk. It may be obtained in large quantities by evaporating whey to a syrupy consistency, when the lactose separates by crystallization. The lactose so obtained is subsequently purified by the aid of animal charcoal.

Lactose crystallizes in white needle-shaped crystals of great hardness. It dissolves but slowly in cold water, and has a slightly sweetish taste.

When milk sugar is distilled with any oxidizing substance, such as manganese dioxide, formic acid is formed.

445. Starch, $C_6H_{10}O_5$, is one of the most important of the proximate principles of plants, and as such is widely distributed through the vegetable kingdom. It is especially abundant in the cereals, and in such roots or tubers as the potato, etc. In order to obtain it, the grain or root is crushed and washed in cold water on a sieve. By this means the cellular tissue is retained, while the starch passes through suspended in the liquid, from which it settles as a soft white powder.

Starch, when examined by the microscope, is seen to consist of granules that possess definite organic structure, of the form shown largely magnified in Fig. 141. These granules consist of concentric layers, as becomes evident when they are treated with sufficiently hot water, which causes them to swell and burst, as shown in Fig. 142. The mealiness of a boiled potato is occasioned by the bursting of these granules or feculæ, as they are often called.

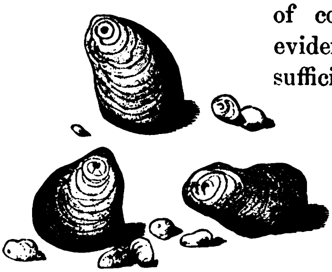


Fig. 141.—Starch Granules.

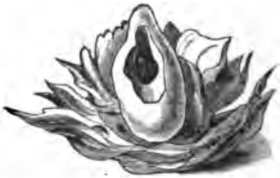


Fig. 142.—Starch Granules, swollen.

Starch is not soluble in water, but when boiled in excess of water, and the liquid is filtered, a small quantity of minute particles passes through the filter, together with a little of a soluble variety of starch, and forms what is called *solution of* *starch.* This solution is used as a test for iodine, by which it is colored a deep blue.

446. Dextrin.—By the prolonged action of boiling water, starch is converted into a soluble variety, which, as we have seen, is colored blue by iodine. At a higher temperature it loses this property, and is converted into dextrin, which is the material employed for mucilage.

By prolonged boiling with acid, dextrin is converted into glucose.

Starches are also converted into dextrin and glucose by the action of a ferment called diastase.

447. Cellulose, $C_6H_{10}O_5$, **or Lignin,** forms the material of which all the cells and vessels of plants are formed. It therefore exists in large amounts in all vegetable matter. It differs, however, from the ligneous or woody fibre. Cellulose has the same composition as starch. Cellulose forms almost the entire structure in pure linen and cotton. It also forms the basis of all papers. It is insoluble in water, and is not affected by acids, unless they are strong. By long boiling with strong sulphuric acid, it is converted into a substance resembling dextrin.

448. Gun-Cotton, $C_6H_7(NO_2)_3O_5$, **or Trinitro Cellulose,** is obtained by steeping finely divided cellulose, such as cotton wool, for a few moments in a mixture of sulphuric and nitric acids, and then removing the acid and thoroughly washing and drying. It contains oxygen sufficient for its own combustion, and is explosive when detonated in a confined space.

449. Gums are substances widely distributed throughout the vegetable kingdom. They dissolve or swell in water, producing a viscid or mucilaginous solution. *Mucilages* resemble gums, but are not as soluble.

Gum-arabic is obtained from several species of acacia. It is destitute of crystalline structure, and breaks with a conchoidal fracture. It is quite soluble in cold water.

Mucilage exists in great abundance in linseed. *Gum-tragacanth* is a variety of mucilage. *Pectin*, or the jelly of fruits, is closely connected with the preceding bodies.

SYLLABUS.

In the dyad paraffine radicals, CH_2; C_2H_4, C_3H_6, C_4H_8, etc., the substitutions may occur on the same carbon stem, or on two separate carbon stems.

The aldehydes are compounds in which the two free bonds on a terminal carbon atom are closed by a single oxygen atom.

The ketones are compounds in which both substitutions occur on an intermediate carbon atom that is linked to one of the carbon atoms in each of two alcohol radicals.

The glycols, or diacid alcohols, are compounds in which both of the free bonds are closed by a hydroxyl group.

The aldehydes are generally obtained by the oxidation of the alcohols. One atom of oxygen removes two hydrogen atoms. The name aldehyde is derived from the fact that these bodies are dehydrogenated alcohol.

Methylic aldehyde, CH_2O, is obtained by the oxidation of methylic alcohol by causing its vapor mixed with air to impinge against a heated platinum spiral.

Ethylic aldehyde, or simple aldehyde, is a mobile, colorless liquid, possessing a peculiar ethereal odor. It is inflammable in the air.

Trichloraldehyde or chloral is extensively employed in medicine as a hypnotic and an anodyne. It is produced by the action of chlorine on ordinary alcohol.

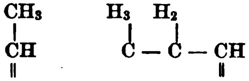
Chloral is a colorless, mobile, oily liquid, possessing a peculiar, penetrating odor.

Acrolein, or acrylic aldehyde, is formed by the destructive distillation of fats or glycerine.

Œnanthic aldehyde is obtained from castor-oil. It is an oily liquid, having a disagreeable smell. Palmitic and stearic aldehydes are solid, crystalline bodies.

The aldehydes are intermediate between the alcohols and the fatty acids, and may be converted into either of these substances.

The dyad radicals,



$$\begin{array}{c} CH_3 \\ | \\ CH \\ \| \end{array} \qquad \begin{array}{ccccc} H_3 & & H_2 & & \\ | & & | & & \\ C & - & C & - & CH \\ & & & & \| \end{array}$$

or the aldehyde radicals, are called ethylidene, propylidene, etc. They form a variety of substitution compounds.

The aldehyde radicals may be linked by oxygen atoms to monad alcohol radicals, thus forming ethereal compounds.

Acetone, or dimethyl ketone, C_3H_6O, is prepared by the dry distillation of calcium acetate. It is a colorless, mobile liquid, that mixes readily with alcohol, ether, and water, and is a solvent for fats.

The lowest glycol is ethylene glycol, a colorless liquid, having a sweetish, alcoholic taste. Like the monatomic alcohols, the glycols are converted into acids by oxidation.

Lactic acid exists in sour milk. It is homologous with glycolic acid. It is produced during a peculiar kind of fermentation, called lactic fermentation. Lactic acid is a colorless, syrupy liquid, possessing an intensely sour taste.

The diatomic ammonias or diamines result from the replacement of the hydroxyl groups by the compound radical amine, NH_2.

The trivalent paraffine radicals, CH, C_2H_3, C_3H_5, C_4H_7, etc., may have the three substitutions occur on one, two, or three different atoms; the most important compounds so produced are the fatty acids and the glyceryls.

Chloroform, $CHCl_3$, or formyl trichloride, is obtained by the distillation of a mixture of alcohol and bleaching powder. It is a colorless, mobile liquid, with a burning taste, and an agreeable ethereal smell. It is used in medicine as an anæsthetic.

The fatty acids are compounds produced by two of the free bonds of the trivalent paraffine radicals being saturated by a single oxygen atom, and the remaining bond by a hydroxyl group.

Some of these acids are formic, acetic, propionic, butyric, valeric, caproic, œnanthylic, and caprylic.

Formic acids exist free in the bodies of ants and in the stinging-nettle. It may be obtained by the action of heat on oxalic acid.

Acetic acid is the acid of vinegar. It is generally obtained by the oxidation of ordinary alcohol, or by the destructive distillation of wood.

Acetic acid is a colorless, mobile liquid, possessing strongly corrosive properties and a pungent taste.

Vinegar is obtained by the fermentation of dilute alcohol. Yeast, or putrescible nitrogeneous matter, produces in the alcohol a peculiar ferment called mother of vinegar.

The salts of acetic acid are called the acetates. The acetates form a large and important class of salts. They may contain one or two molecules of acetic acid.

Acetic anhydride, or anhydrous acetic acid, is a heavy oily substance, obtained by the action of potassium acetate on acetyl chloride.

Acetamide is a solid crystalline substance, having the peculiar odor of mice.

Propionic acid is a colorless, oily liquid, somewhat resembling acetic acid. Its name is derived from the circumstance that it forms the first fat of the series of the so-called fatty acids. It is produced along with acetic acid during the distillation of wood.

Butyric acid occurs as fat in butter. It is a mobile, colorless liquid, with a disagreeable odor, and a strong acid taste.

Valeric acid derives its name from the valerian root, from whence it is obtained by distillation. It is a colorless, acid liquid, having a peculiarly disagreeable odor.

Caproic acid is an oily liquid, possessing an odor faintly resembling sweat.

Œnanthylic acid is a colorless, oily liquid, obtained from castor-oil.

Most of the remaining acids of the series are obtained from the various vegetable and animal fats and oils.

Fats are compounds of the different fatty acids with glycerine.

Caprylic acid exists in butter, cocoa-nut-oil, and in various vegetable fats. Its odor resembles that of sweat.

Pelargonic acid is obtained from the geranium, and from oil of rue. Though the acid itself has an unpleasant smell, yet its ether is pleasant in odor, and, in fact, gives the peculiar bouquet to many wines.

Capric acid is a solid; it exists in butter, cocoa-nut-oil, and in many vegetable fats.

Palmitic acid is a solid, and exists in nearly all vegetable and animal fats, associated in the latter with stearic and oleic acids.

Stearic acid is one of the principal ingredients of the more solid of the animal fats. It is nearly always associated with palmitic acid. These acids are prepared, in large quantities, for the manufacture of stearine candles, by decomposing the fats by superheated steam, and separating the solid acids from the glycerine by strong pressure.

Cerotic acid exists in beeswax.

When the fatty acids are mixed with the alcohols and heated, various compound ethers are produced, by the alcohol radicals replacing some of the hydrogen of the acids. These ethers are nearly all characterized by agreeable odors, and are largely used in confectionery and cheap perfumery.

Amyl acetate has an odor resembling that of the Jargonelle pear.

Ethyl butyrate has an odor resembling that of fresh pine-apples.

Amyl valerate has an odor resembling that of apples.

Spermaceti consists largely of cetylic palmitate. Beeswax consists largely of melissylic palmitate.

Glyceryl is the name given to the trivalent compound radical C_3H_5. When its three bonds are satisfied with hydroxyl, glycerine is produced.

Glycerine is readily obtained from the natural oils, or fats, by decomposing them by means of heated steam, or by boiling them with powerful basic hydrates. The hydrates combine with and saponify the fatty acids; that is, form compounds with them called soaps, and thus set free the glycerine.

Pure glycerine is a colorless, viscid liquid, possessing a sweetish taste, and capable of mixing with water in every proportion.

Soaps are mixtures of potassium and sodium salts of the fatty acids. They may be divided into hard and soft soaps. The hard soaps are mainly sodium salts of palmitic, oleic, or stearic acids. The soft soaps are potassium salts of fatty acids.

When dissolved in an excess of water, soaps are decomposed into the fatty acids and free alkali.

All or any of the hydroxyl groups in glycerine may be replaced by monivalent atoms or radicals, thus producing a great variety of derivatives.

Trinitroglycerine is a dangerously explosive substance obtained by gradually dropping glycerine into a cooled mixture of strong nitric and sulphuric acids. It is a poisonous, yellowish oil. When mixed with fine sand it forms a substance called dynamite.

Most of the vegetable and animal fats contain more than one fatty acid combined with the glycerine.

Drying oils are such as contain acids that readily oxidize on exposure to the air, and are thus converted into substances resembling resins.

Oxalic acid exists in many plants and in the urine of animals. It may be obtained by the action of caustic potash on wood-shavings or sawdust, or by the oxidizing action of nitric acid on molasses. Oxalic acid is very poisonous. Its antidote is milk of lime.

Succinic acid, originally obtained by the distillation of amber, is formed by the oxidation of palmitic or stearic acid by nitric acid.

Among the most important of the numerous substances derived from the higher alcohol radicals are malic, tartaric, and citric acids, and the carbohydrates.

Malic acid exists in sour apples, quinces, gooseberries, and cranberries.

Tartaric acid is the acid of grapes and is principally obtained from the tartar or argol of the wine-casks.

Cream of tartar, or potassium acid tartrate, is used in connection with sodium carbonate as a baking powder.

Tartar emetic, or antimonio-potassium tartrate is a poisonous substance that is used in small quantities as an emetic.

Citric acid is the acid of oranges, lemons, and limes. It is used in making acid drinks.

Uric acid exists in urinary calculi; in the excreta of serpents, and in guano. Heated in small amount with nitric acid, and gently evaporated, the residue yields a purple substance called murexide.

The carbo-hydrates are bodies in which the carbon nucleus is combined with hydrogen and oxygen in the proportion to form water. This group includes a great variety of substances. The most important are various sugars, starches, and gums.

Glucose is the most important of the sugars; it exists in dried fruits and in honey. It is manufactured in large quantities by the action of sulphuric or hydrochloric acid on starch.

Maltose and levulose are varieties of glucose.

Saccharose or cane-sugar is obtained from the sugar-cane, sugar-maple, or sugar-beet, from which it is extracted by heating the expressed juice to near its boiling-point. The raw sugar so obtained is afterwards purified by a process known as refining.

Molasses is a mixture of glucose and levulose. It is formed when saccharose is boiled for a long while with dilute acid.

Starch is one of the most important proximate principles of plants. It is obtained from the cereals and certain roots or tubers by crushing them and washing in cold water.

Lactose, or milk sugar, exists dissolved in milk, from which it may be obtained by evaporating the whey.

Starch consists of minute granules or feculæ formed of numerous consecutive layers. On heating, these feculæ burst, causing the granules to swell greatly.

Dextrine is a substance having the same composition as starch. It is formed by prolonged heating of starch in water.

Cellulose or lignin is the material of which the cells and vessels of all kinds of plants are formed. Linen consists of very nearly pure cellulose.

Trinitrocellulose, or gun-cotton, is obtained by steeping cotton wool in a mixture of nitric and sulphuric acids.

Gums are vegetable substances that dissolve in water and impart to it a mucilaginous or viscid consistency. Gum-arabic is one of the most important.

Mucilages resemble gums, but are less soluble in water. Gum-tragacanth is a mucilage.

QUESTIONS FOR REVIEW.

Write graphic formulæ for the first four dyad paraffine radicals.

How and where are the substitutions made in the aldehydes? Write the graphic formulæ for any two of the aldehydes.

How and where do the substitutions occur in the ketones? Write the graphic formula for acetone.

How and where do the substitutions occur in the glycols or diacid alcohols? Write the graphic formulæ for ethylene glycol and tricarbon glycol.

How are the aldehydes generally produced? What is the derivation of the word aldehyde?

Which contain the greater proportion of oxygen, the acids or the aldehydes?

How is methylic aldehyde prepared? Describe its properties.

Describe the manner in which common aldehyde is prepared. What are its properties? Why is it sometimes called acetic aldehyde?

What is the composition of trichloraldehyde or chloral? How is chloral obtained? What are its properties? Under what circumstances does chloral become insoluble?

What is the composition of acrolein or acrylic aldehyde? Name some of its properties.

Write the chemical formulæ for butyric, œnanthylic, and palmitic aldehydes.

In what respects do the aldehydes occupy an intermediate position between the alcohols and the fatty acids?

What is meant by the aldehyde radicals? What is the formulæ of ethylidene? Propylidene?

In what respects do the ethereal compounds of the aldehyde radicals resemble the ordinary ethers of the alcohols?

How are the ketones derived? Describe the preparation and properties of acetone or dimethyl ketone.

How are the glycols produced? What are their general properties? Describe the preparation and properties of glycol or ethylene dihydrate.

What is the natural source of lactic acid? How is lactic acid produced artificially? State some of its properties.

What is the origin of glycolic acid? Explain the manner in which the ethers of the glycols are produced.

Explain the manner in which the diatomic ammonias, or diamines, are produced.

Write graphic formulæ for the first four of the trivalent paraffine radicals. In what different ways may the substitutions be effected in these radicals?

What is chloroform? How is it produced? What are its properties?

How are the fatty acids derived from the trivalent paraffine radicals? Write graphic formulæ for the first five of the fatty acids.

Write the names and formulæ for fifteen of the fatty acids. How do the physical properties of the acids relatively poor in carbon differ from the properties of those rich in carbon?

Where does formic acid exist free in nature? What are the properties of formic acid? How may it be produced artificially?

How is acetic acid produced? What are its properties? In what common substance does it exist? How may it be produced on a commercial scale?

Describe the ordinary process for the manufacture of vinegar. Describe the quick vinegar process. What is mother of vinegar?

Name some of the more important of the acetates and write their chemical formulæ. Describe some of their properties.

How is acetic anhydride obtained? What are its properties? How is acetamide produced? What are its properties?

What is the origin of the name of propionic acid? How is it produced?

Describe the properties of butyric acid. What is its chief source? Write its formula.

Describe the properties of valeric acid. What is its principal origin?

Describe the properties of caproic and œnanthylic acids. Of caprylic and pelargonic acids.

Name the principal fatty acids that exist in the animal fats and oils.

How are the solid fatty acids separated from the glycerine with which they are combined in natural fats and oils?

Describe the manner in which ethereal salts, or compound ethers, are derived from the fatty acids. What general property do most of these substances possess?

Write the formulæ for some of the compound ethers and state what peculiarity their odor possesses.

Write the graphic formula for the compound radical glyceryl. How is glycerine obtained? What is nitro-glycerine?

Name some of the most important of the derivatives of the higher alcohol radicals.

What are the natural sources of oxalic acid? In what different ways is oxalic acid prepared artificially? Describe some of the properties of oxalic acid. What is the antidote for oxalic acid?

What is the source of malic acid? Describe some of its properties.

From what source is tartaric acid derived? Describe its properties.

What is the composition of cream of tartar? For what is it largely used?

What is the composition of tartar emetic? From what source is citric acid obtained?

What are the natural sources of uric acid? How may it be obtained artificially? What are its properties? Describe a characteristic test for uric acid.

Describe the characteristics of the group of the carbo-hydrates. Name the principal substances belonging to this group.

What are the principal natural sources of glucose? How is it obtained artificially? What are some of its varieties?

What are the principal natural sources of saccharose? How is the raw sugar obtained? Describe briefly the process of refining.

What is the natural source of lactose, or milk sugar? What are its properties?

What are the sources of starch? What is its composition? Describe the appearance and structure of the granules or feculæ. What effect is produced on a starch solution by iodine?

What is dextrine? How is it prepared? For what is it employed?

What is cellulose? What are its sources? In what common substances does it exist? How is it converted into gun-cotton?

Describe the general properties of gums. Of mucilages.

SECTION III.

THE DOUBLE- AND TRIPLE-LINKED CARBON NUCLEI.

CHAPTER VI.

THE DOUBLE- AND TRIPLE-LINKED CARBON NUCLEI.

450. Characteristics of the Group.—The carbon atom, instead of having all its four bonds satisfied by being united with the atoms of other substances, may have two or three of its bonds closed by another carbon atom. The double- and triple-linked carbon nuclei thus result. As we have already seen, these compounds are unsaturated, and can combine directly with hydrogen or the haloids, or their hydracids. In such cases one of the bonds of the carbon nucleus is broken.

451. The Double-Linked Carbon Nuclei.—The Olefines.—All the members of this group contain twice as many hydrogen atoms as carbon atoms. Their general formula, therefore, is C_nH_{2n}. They are all, up to C_5, gases at ordinary temperatures. The higher members are solids, and the intermediate ones liquid. They occur in small quantities in the gases emanating from oil wells; from natural gas wells, and in ordinary illuminating gas.

Since one of the double bonds between the two carbon atoms is loosened during combination, leaving a free bond for each carbon atom, these hydrocarbons are diatomic.

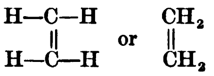
The general term olefines has been applied to this group from the oily nature of the chlorides and the bromides.

452. Members of the Group of the Olefines.—The following are among the more important members of the double-linked carbon compounds, viz.:

CH_2, Methylene (unknown).
C_2H_4, Ethylene.
C_3H_6, Propylene.
C_4H_8, Butylene.
C_5H_{10}, Amylene.

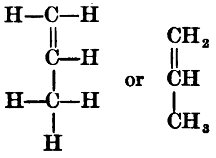
Higher members of this group exist.

The following will show the double linking of the groups, viz.:



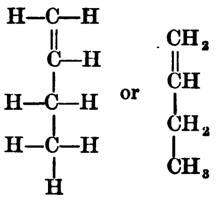
$$\begin{array}{c} \mathrm{H{-}C{-}H} \\ \| \\ \mathrm{H{-}C{-}H} \end{array} \quad \text{or} \quad \begin{array}{c} CH_2 \\ \| \\ CH_2 \end{array}$$

Ethylene.



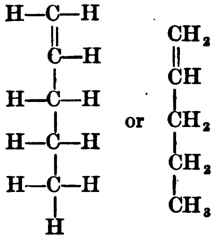
$$\begin{array}{c} \mathrm{H{-}C{-}H} \\ \| \\ \mathrm{C{-}H} \\ | \\ \mathrm{H{-}C{-}H} \\ | \\ \mathrm{H} \end{array} \quad \text{or} \quad \begin{array}{c} CH_2 \\ \| \\ CH \\ | \\ CH_3 \end{array}$$

Propylene.



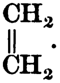
$$\begin{array}{c} \mathrm{H{-}C{-}H} \\ \| \\ \mathrm{C{-}H} \\ | \\ \mathrm{H{-}C{-}H} \\ | \\ \mathrm{H{-}C{-}H} \\ | \\ \mathrm{H} \end{array} \quad \text{or} \quad \begin{array}{c} CH_2 \\ \| \\ CH \\ | \\ CH_2 \\ | \\ CH_3 \end{array}$$

Butylene.



$$\begin{array}{c} \mathrm{H{-}C{-}H} \\ \| \\ \mathrm{C{-}H} \\ | \\ \mathrm{H{-}C{-}H} \\ | \\ \mathrm{H{-}C{-}H} \\ | \\ \mathrm{H{-}C{-}H} \\ | \\ \mathrm{H} \end{array} \quad \text{or} \quad \begin{array}{c} CH_2 \\ \| \\ CH \\ | \\ CH_2 \\ | \\ CH_2 \\ | \\ CH_3 \end{array}$$

Amylene.

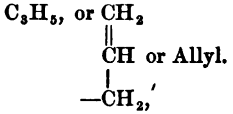
453. Ethylene, C_2H_4 or  $\begin{array}{c} CH_2 \\ \| \\ CH_2 \end{array}$. *Ethene*, or *olefiant gas.*—This body is the first member of the series, since CH_2 is of course impossible. Ethylene is obtained by subjecting wood, fats, resins, oils, etc., to dry distillation. It may be readily prepared by subjecting a mixture of ethylic alcohol and sulphuric acid to the action of heat. It is a colorless gas, that is but sparingly soluble in water, and burns in the air with a bright white light. Mixed with oxygen it explodes violently when ignited. Its density is .98. Its odor faintly resembles that of garlic.

Ethylene unites directly with chlorine, producing a heavy, oily liquid, called Dutch liquid, which has a sweetish taste and an agreeable odor. Ethylene also combines directly with iodine and bromine.

454. Propylene, C_3H_6 **or** $CH_2 = CH.CH_3$.—Propylene is generally produced during the dry distillation of organic substances. It is a gaseous substance, somewhat resembling ethylene, but is much heavier, its density being 1.49.

Butylene, C_4H_8 or $CH_2 = CH — CH_2.CH_3$, and *Amylene,* C_5H_{10} or $CH_2 = CH.CH_2.CH_2.CH_3$, are comparatively unimportant. There are three butylenes and five amylenes.

455. Allyl and its Compounds.—The radical



$$C_3H_5, \text{ or } \begin{matrix} CH_2 \\ \| \\ CH \\ | \\ —CH_2,' \end{matrix} \text{ or Allyl.}$$

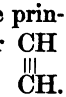
contains one hydrogen atom less than propylene.

This radical forms a number of compounds. With sulphur, as *diallyl sulphide,* it occurs in nature in onions and leeks, and is called *oil of garlic.*

Allyl sulphocyanate, or *oil of mustard,* is a transparent, oily substance, that possesses in a very marked degree the penetrating odor of mustard, and, like that substance, readily excites tears. It may be obtained by the distillation of the seeds of black mustard in water.

Oleic acid, $C_{18}H_{34}O_2$, is an oily liquid obtained from olein, the principal constituent of numerous oils and fats. It contains two atoms of hydrogen less than stearic acid.

456. Triple-Linked Carbon Nuclei: Acetylene.—The principal member of this group is *Acetylene,* C_2H_2, or



$$\begin{matrix} CH \\ ||| \\ CH. \end{matrix}$$

This hydrocarbon may be formed by the direct union of its constituent elements. It is formed whenever the voltaic arc is formed between carbon electrodes in an atmosphere of hydrogen. It is produced during the destructive distillation of nearly all organic substances at a high temperature.

Acetylene is a colorless gas, that burns in the air with a strongly luminous, but smoky flame. It possesses a very disagreeable odor.

When acetylene is passed over certain metals while heated, a characteristic replacement of the hydrogen is effected. This occurs with silver, copper, and the alkali metals. The compounds thus formed with copper and silver are explosive. Explosions have been caused by the copper compound forming in gas-pipes.

SYLLABUS.

In the double- or triple-linked carbon nuclei, since the carbon atoms are unsaturated, they can combine directly with hydrogen or the haloids.

The double-linked carbon nuclei form a class of substances called the olefines, from the oily nature of their chlorides or bromides.

All the olefines contain twice as many hydrogen atoms as they do carbon atoms. They are all diatomic.

The most important members of the olefines are ethylene, propylene, butylene, and amylene.

Ethylene, ethene, or olefiant gas, is obtained by submitting wood, fats, resins, oils, etc., to dry distillation. It is a colorless gas, that is but sparingly soluble in water. It burns in the air with a luminous flame.

Dutch liquid, or ethylene chloride, is an oily liquid, with a sweetish taste, and an agreeable odor, formed by the direct union of ethylene and chlorine.

Propylene is another product formed during the dry distillation of wood. It is a gaseous substance, somewhat resembling ethylene. Butylene and amylene are comparatively unimportant.

Allyl is a radical that contains one hydrogen atom less than propylene. It forms a number of compounds with sulphur. Diallyl sulphide occurs in nature in onions and leeks. It is called oil of garlic.

Allyl sulphocyanate, or oil of mustard, is a substance that possesses, in a remarkable degree, the penetrating odor of mustard.

Oleic acid is an oily liquid, which is an important constituent of many oils and fats.

The principal member of the triple-linked carbon nuclei is acetylene.

Acetylene has been formed by the direct union of its constituent elements, by passing the voltaic arc between carbon electrodes in an atmosphere of hydrogen.

Acetylene is a colorless gas, of a disagreeable odor, that burns in the air with a smoky flame.

QUESTIONS FOR REVIEW.

Describe the nature of the linking of the carbon atoms in the double- and triple-linked carbon nuclei.

Why can these substances combine directly with hydrogen or the haloids?

Describe the general nature of the olefines. What is the origin of this name? What are the principal natural sources of the olefines?

Name some of the members of the olefine group.

Describe the general properties of ethylene. What other names are sometimes given to this substance? How may ethylene be conveniently prepared?

What is the composition of Dutch liquid? Describe some of its properties.

How is propylene prepared? Describe some of its properties.

What may be considered the origin of the radical allyl? What is the composition of oil of garlic? of oil of mustard?

What is the composition of oleic acid? What is its principal natural source?

What is the principal member of the group of triple-linked carbon nuclei? How is acetylene prepared? What are its properties?

With what metals does acetylene form explosive compounds?

SECTION IV.

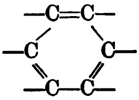
THE CLOSED-CHAIN CARBON NUCLEI.

CHAPTER VII.

THE AROMATIC COMPOUNDS.

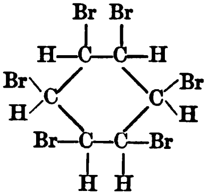
457. The Aromatic Compounds.—The benzol, or benzine nucleus, C_6H_6, forms a great variety of substitution compounds. The first of these that were obtained possessed marked aromatic odor, and thus gave the name to the group. Later discoveries have shown the existence of numerous other compounds, many of which do not possess the marked odor characteristic of the rest of the group. The name "aromatic compounds," however, serves, like the term "fatty acids," to designate a well-marked group, and has therefore been retained.

458. The Benzol, or Aromatic Nucleus.—It would appear that the carbon nucleus of this series exists in the form of a ring or closed chain, in which the carbon atoms in the chain are connected by alternate single and double linking, the whole being in the form of a closed ring or chain, thus:



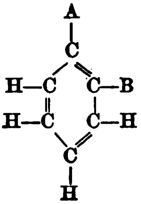
This, it will be seen, leaves each carbon atom with but one free bond.

There are many reasons for believing that the carbon atoms in the benzol nucleus have this peculiar grouping. Perhaps the most striking is the fact that but six atoms of chlorine, bromine, or other univalent element can be caused to combine with the nucleus, thus:

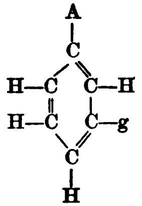


459. Additive Compounds.—Benzol being an unsaturated compound, yields *additive compounds.* Thus bromine, etc., enters directly into combination with the benzol, by one of the double links of two contiguous carbon atoms being freed, thus leaving two free bonds. Two, four, or six univalent atoms may thus be added to the benzol nucleus; thus, C_6H_6-Br_6, $C_6H_6Br_4$, $C_6H_6Br_2$; so also, $C_6H_6Cl_6$. Benzol hexabromide and benzol hexachloride crystallize in colorless crystals.

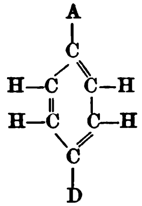
460. Substitution Compounds.—Various substitution compounds are obtained by replacing one or more of its hydrogen atoms by univalent atoms, or compound radicals. Where only one atom is thus replaced, its position appears to make no difference in the nature of the resulting compound, but when two are thus replaced a number of isomeric compounds are produced, depending on whether the replaced hydrogen atoms are contiguous, alternate, or removed from one another as far as possible.



Contiguous replacements, thus, at A and B, produce compounds that are called *ortho derivatives.*



Alternate replacements, thus, at A and g, produce compounds that are called *meta derivatives.*



When the replaced hydrogen atoms are as far removed as possible, thus at A and D, the resulting compounds are called *para derivatives.*

When more than two of the hydrogen atoms are replaced, the number of possible isomeric compounds is greatly increased.

461. Benzol.—This compound is produced synthetically, when acetylene is passed through white hot tubes. It is obtained commercially by the fractional distillation of coal-tar. It comes off with the light oils. Benzol is a mobile, colorless liquid, possessing a characteristic penetrating odor. Its specific gravity is .899. Though almost insoluble in water, it readily imparts its peculiar odor to it. It possesses valuable solvent powers for fats and resins, and for caoutchouc and india-rubber. It is inflammable in air, burning with a smoky flame.

462. Substitution Compounds.—*Monobromo benzol,* C_6H_5Br, is produced by the substitution of one hydrogen atom. It is obtained by mixing benzol with bromine in the proper proportions. It is a colorless liquid.

Dibromo benzol, $C_6H_4Br_2$, is obtained by the action of an excess of bromine on benzol. It is a crystalline solid.

Nitro benzol, $C_6H_5(NO_2)$, is obtained by the action of strong nitric acid on benzol. It is a yellowish liquid, which possesses an odor very similar to oil of bitter almonds, for which it is often substituted in perfumery. By the action of a reducing agent this compound is converted into amidobenzol or aniline. $C_6H_5(NH_2)$, thus:

$$C_6H_5(NO_2) + 3H_2 = 2H_2O + C_6H_5(NH_2)$$

Nitrobenzol + Hydrogen = Water + Aniline.

Benzol may have two or three of its hydrogen atoms replaced by hydroxyl groups, thus:

C_6H_6	C_6H_5OH	$C_6H_4(OH)_2$	$C_6H_3(OH)_3$
Benzol.	Phenol.	Oxyphenol.	Phloroglucin.

These substances correspond with the following, viz.:

C_3H_8	$C_3H_7.OH$	$C_3H_6(OH)_2$	$C_3H_5(OH)_3$
Propane.	Propyl Alcohol.	Propyl Glycol.	Glycerine.

463. Carbolic Acid, C_6H_5OH, *hydroxy-benzol*, *phenyl hydrate*, or *phenol*, is a substitution compound, in which one atom of hydrogen is replaced by hydroxyl. It occurs in heavy coal-tar. It is, therefore, an alcohol of the benzol nucleus.

Carbolic acid may readily be obtained from coal-tar by distillation, or from heavy coal-oils by agitation with strong solution of soda.

Pure carbolic acid, or phenol, occurs in colorless crystals, readily soluble in water or alcohol. They have a peculiar and characteristic odor, and a burning, caustic taste. Carbolic acid acts energetically on the skin, destroying it, and is a powerful poison. It is largely employed as a disinfectant, and acts as an antiseptic, a preservative of animal substances, by its ability to kill the germs that cause putrefactive decay. During the smoking of meat, a small quantity of carbolic acid is formed in the smoke.

Carbolic acid dissolved in water yields a characteristic violet color with a solution of ferric chloride.

464. Aniline, $C_6H_5NH_2$, is obtained as one of the products of the distillation of coal-tar. Its production from nitrobenzol, by the reducing action of nascent hydrogen, has already been referred to.

Aniline is a colorless, mobile liquid, whose specific gravity is 1.036. It has a faint but peculiar smell. It is slightly soluble in water, but freely soluble in alcohol or ether, and in the volatile fatty oils. It acts as an alkaloid, forming salts with the acids. Aniline forms the basis of a magnificent series of dyes, largely employed in the arts.

465. **Trinitrophenol,** or *picric acid,* $C_6H_2(NO_2)_3.OH$. This substance, sometimes called *carbazotic* acid, is obtained by boiling phenol in strong nitric acid, thus:

$$\underset{\text{Phenol}}{C_6H_5OH} + \underset{\text{Nitric Acid}}{3HNO_3} = \underset{\text{Water}}{3H_2O} + \underset{\text{Trinitrophenol.}}{C_6H_2(NO_2)_3.OH}$$

Trinitrophenol, or picric acid, as it is most commonly called, crystallizes in pale-yellow crystalline scales. It is largely employed as a yellow dye. It forms a series of salts with bases, most of which explode with great violence when heated. This is especially the case with the potassium picrate.

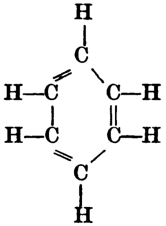
Picric acid is also produced by the action of nitric acid on indigo, and various other organic substances, such as wool, and different resins.

466. **Indigo,** C_8H_5NO, is obtained from the juices of certain plants called the *indigoferæ.* The indigo is prepared on a large scale by making the leaves and stems into a pulp with water, and allowing the pulp to ferment. The resulting liquid is decanted, and deposits, on exposure to the air, an insoluble blue powder, which is the indigo of commerce. Reducing agents, such as $FeSO_4$, convert it into white indigo, which is soluble in alkaline liquids. The fabrics to be dyed with indigo are dipped into this liquid, and afterwards become blue on exposure to the air, which again oxidizes the indigo.

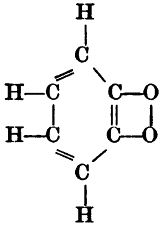
Indigo may be made artificially from phenol, but not, as yet, cheaply enough to compete with the natural product.

467. **Quinone,** $C_6H_4O_2$, results from the oxidation of quinic acid, a constituent of cinchona bark. The oxidation is most conveniently effected by the action of sulphuric acid and manganese dioxide. Quinone crystallizes in brilliant crystals

of a deep yellow. It sublimes at ordinary temperatures, producing a vapor irritating to the eyes. In this compound the oxygen replaces two hydrogen atoms, and is linked to two carbon atoms either by single or double linkage, thus:

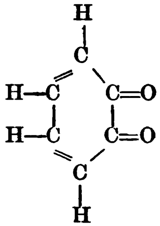


Benzol.



Quinone.

or



Quinone.

468. Toluol, or Methyl-phenyl, $C_6H_5—CH_3$, so named because it exists in balsam of Tolu. It may be obtained by fractional distillation from coal-tar. It is a liquid, whose specific gravity is 0.882. Toluol is converted into benzoic acid by the action of boiling nitric acid. A number of substitution compounds are obtained from toluol.

469. Benzyl Alcohol, $C_6H_5—CH_2OH$, is the aromatic alcohol corresponding to toluol. The corresponding aldehyde of this alcohol is *oil of bitter almonds,* $C_6H_5—CHO$, largely used in confectionery as a flavor. Both these substances yield benzoic acid on oxidation.

470. Toluidine, $C_7H_7(NH_2)$, is a crystalline solid, that is always one of the constituents of commercial aniline. It may be regarded as toluol, in which one of the hydrogen atoms is replaced by the radical NH_2. It may be produced artificially by the action of nascent hydrogen on nitrotoluol, thus:

$$\begin{array}{ccccccccc} C_7H_7(NO_2) & + & 3H_2 & = & C_7H_7(NH_2) & + & 2H_2O \\ \text{Nitrotoluol} & + & \text{Hydrogen} & = & \text{Toluidine} & + & \text{Water.} \end{array}$$

471. Rosaniline, $C_{20}H_{19}N_3$, is a magnificent coloring matter, which forms the basis of the so-called aniline dyes. It is prepared by heating commercial aniline with arsenic acid. An oxidation results, together with a combination of the aniline and toluidine, thus:

C_6H_7N	+	$2C_7H_9N$	+	O_3	=	$C_{20}H_{19}N_3$	+	$3H_2O$
Aniline	+	Toluidine	+	Oxygen	=	Rosaniline	+	Water.

The resulting product remains combined with arsenic acid, and is separated from it by sodium hydrate, and then dissolved in hydrochloric acid, with which it forms a magnificent crystalline salt of a splendid green color, readily soluble in alcohol, imparting to it a deep red color.

Many of the aniline dyes still retain arsenic acid, a very poisonous substance. In order to avoid the bad effects of this acid, other oxidizing agents have been successfully substituted.

Rosaniline is in itself colorless, but it forms with acids a variety of salts, that possess valuable coloring properties. It is a triacid base. The monochloride, or *fuchsine,* forms the greenish crystals above mentioned, that dissolved in alcohol produce the deep red liquid, already described. The trihydrochloride crystallizes in brownish-yellow needles.

472. Coloring Matters Obtained from Rosaniline.—Rosaniline yields a variety of substitution compounds that form a splendid series of rich dyes. The more important are as follows, viz.:

Hoffmann's violet, or *triethylrosaniline,* obtained by heating rosaniline with ethyl iodide, when three hydrogen atoms are replaced by three ethyl radicals.

Lyons blue, or *hydrochloride of triphenylrosaniline.*

Paris violet, obtained by the oxidation of dimethylaniline.

Night green, so called on account of showing its tint by gaslight.

473. Benzoic Acid, $C_6H_5.CO_2H$. This acid may be regarded as benzol, in which a hydrogen atom is replaced by the group COOH. It exists in gum benzoin, from which it may be obtained by moderately heating the gum for several hours. The acid volatilizes, and may be collected on a sheet of tissue-paper placed inside the paper cone, D, Fig. 143, covering over the vessel containing the gum. Thus prepared, it occurs in the form of feathery, colorless crystals. These crystals emit a very fragrant odor when heated, due, not to the acid itself, but to a volatile liquid mixed with it. The acid is readily soluble in alcohol and ether, and is employed in the manufacture of colognes.

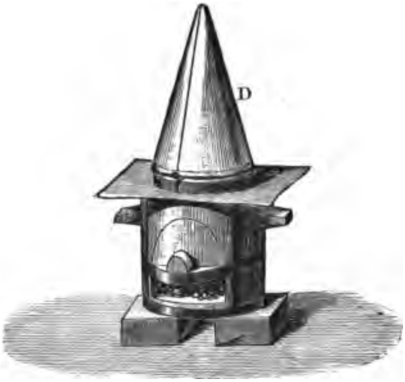


Fig. 143.—Preparation of Benzoic Acid.

Benzoic acid may also be obtained from hippuric acid by decomposing it by hydrochloric acid.

474. Hippuric Acid, $C_9H_9NO_3$, occurs in the urine of cattle. When heated with hydrochloric acid, glycocol and benzoic acid result, thus:

$$\underset{\text{Hippuric Acid}}{C_9H_9NO_3} + \underset{\text{Water}}{H_2O} = \underset{\text{Glycocol}}{C_2H_5NO_2} + \underset{\text{Benzoic Acid.}}{C_7H_6O_2}$$

Hippuric acid occurs in long, slender, milky-white crystals, which have a somewhat bitter taste.

475. Salicyl Hydride, $C_6H_4(OH).CHO$, exists as the essential oil in meadow-sweet, and is isomeric in composition with benzoic acid. It is a mobile, colorless, and very fragrant oil, of the specific gravity of 1.173. It is inflammable in air, and readily soluble in ether and alcohol.

476. Salicylic Acid, $C_6H_4(OH)CO_2H$, occurs naturally in oil of meadow-sweet. It also occurs in oil of winter-green, in combination with methyl, as methyl salicylate. It may be obtained from this oil by boiling it with caustic potash. The potassium salicylate thus formed is then decomposed by hydrochloric acid, when the salicylic acid separates by crystallization.

Salicylic acid possesses in a remarkable degree the properties of an antiseptic, excelling in this respect carbolic acid. Since salicylic acid has but little taste and odor, it is much better for preserving meat, and other foods, than carbolic acid.

477. Anisic Acid, $C_8H_8O_3$, **and Anisic Aldehyde,** $C_8H_8O_2$, occur in oils of anise and fennel. The latter is a colorless oil possessing a fragrant spicy odor.

478. Gallic Acid, $C_6H_2(OH)_3.COOH$, is obtained by the gradual oxidation of moistened nut-galls, as by exposing them to the air for a long time. The acid is obtained by allowing the dark blackish liquid thus formed to crystallize, when the gallic acid separates in silken needle-shaped masses. Gallic acid is soluble in water and alcohol, especially the latter.

479. Digallic Acid, or Tannin, $C_{14}H_{10}O_9$, or, as it is commonly called, tannic acid, is obtained from nut-galls by powdering them and extracting with ordinary ether. The liquid separates into two layers, the lower of which is a strong aqueous solution of tannin. When the water is evaporated the tannin remains as a light-yellow amorphous powder, very soluble in water, and less soluble in alcohol. It has an astringent taste, and gives a black precipitate with ferric salts. This precipitate is exceedingly fine and remains suspended in the liquid. Ink usually consists of ferric tannate, formed by the action of an iron salt on nut-galls, with the addition of a little gum.

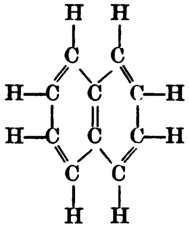
480. The Terpenes, $C_{10}H_{16}$, **or the Essential Oils,** prominent among which are the oils of turpentine, lemon, orange-flower, peppermint, and cloves, belong to the aromatic series, and, in fact, gave to it its name. Their constitution, however, is somewhat doubtful. These oils are all isomeric, and have composition $C_{10}H_{16}$, and change spontaneously into an oil like turpentine. They are obtained by distilling resin or the leaves of plants with water. The distillate separates into a layer of oil and a layer of water. They boil at about 320°, are insoluble in water, and burn in air with a smoky flame.

481. Camphor, $C_{10}H_{16}O$, is derived from the wood of the *laurus camphora*, by distilling it with water. It is probably an aldehyde, and can be converted into Borneo camphor, $C_{10}H_{18}O$, which appears to be the corresponding alcohol.

Experiment 86.—If a few fragments of clean camphor be thrown on the surface of water in a vessel quite free from grease, they will swim rapidly over the surface in an amusing manner. These motions are due to the gradual solution of the camphor, and are instantly stopped by the addition to the water of a small amount of grease.

482. Naphthalene, $C_{10}H_8$, *and its Derivatives.*—This substance may be regarded as a compound containing condensed benzole nuclei. The carbon atoms are arranged in two or more closed chains, forming two rings; thus:

Naphthalene and anthracene, $C_{14}H_{10}$, are solid hydrocarbons derived from coal-tar. They form the basis for the formation of a magnificent series of coloring matters, that are derived from them by complicated processes. Anthracene is the starting-point for making artificial madder dyes.



Naphthalene.

* * *

SYLLABUS.

The closed-chain carbon nuclei form a series of compounds, to which the general name of the aromatic compounds has been given, from the marked aromatic odor of some of the members of the group.

In the benzol, or aromatic nucleus, the carbon atoms of the nucleus are connected by alternate single and double linking; that is, each atom is connected on one side by a single bond, and on the other by two bonds, thus leaving but one free bond.

Compounds containing a closed-chain carbon nucleus, being unsaturated, enter directly into combination with radicals. They therefore form with them additive compounds. Various substitution compounds, however, are obtained by replacing one or more of the hydrogen atoms by univalent atoms or radicals.

Benzol is produced synthetically by passing acetylene through white-hot tubes. It is produced commercially by the fractional distillation of coal-tar. It is a mobile, colorless liquid, with a peculiar penetrating odor. It burns in air with a smoky flame, and is an excellent solvent for fats, resins, and caoutchouc.

Nitrobenzol is a substitution compound obtained by the action of strong nitric acid on benzol. It has an odor resembling that of oil of bitter almonds.

Nitrobenzol is converted into aniline by the action of a reducing agent.

Carbolic acid, or phenol, is a substitution compound of benzol, in which one of the hydrogen atoms is replaced by hydroxyl, and is sometimes called hydroxyl-benzol.

Carbolic acid may be obtained from coal-tar by distillation. When pure it is a colorless substance, possessing the peculiar odor of creosote. It has a burning, caustic taste, acts vigorously on the skin, and is a powerful poison.

Carbolic acid is extensively used as a disinfectant and antiseptic.

Carbolic acid imparts a characteristic violet color to an aqueous solution of ferric chloride.

Aniline is obtained as one of the products of the distillation of coal-tar. It is a colorless, mobile liquid, and forms the basis of a magnificent series of dyes, that are largely employed in the arts.

Picric acid, or trinitrophenol, or carbazotic acid, obtained by boiling phenol in strong nitric acid, is largely employed as a yellow dye. It forms a series of explosive salts with bases.

Indigo is obtained from the juices of certain plants. The pulp, made from the leaves and stems, is allowed to ferment. The decanted liquid deposits, on exposure to the air, a blue powder, which is commercial indigo.

Fabrics to be dyed with indigo are dipped into a colorless solution of indigo in an alkaline liquid, and afterwards become blue on exposure to the air.

Quinone results from the oxidation of quinic acid, a constituent of cinchona bark.

Toluol, or methylphenyl, is a liquid substance obtained by the fractional distillation of coal-tar. It is converted into benzoic acid by the action of boiling nitric acid.

Benzyl alcohol is the aromatic alcohol corresponding to toluol. Its corresponding aldehyde is oil of bitter almonds.

Toluidine is a crystalline solid, that is always one of the constituents of commercial aniline.

Rosaniline is a magnificent coloring matter, which forms the basis of the so-called aniline dyes. It is prepared by heating aniline with arsenic acid. Rosaniline is itself colorless, but forms with acids a number of magnificently-colored salts.

The principal coloring matters obtained from rosaniline are Hoffmann's violet, Lyons blue, Paris violet, and night-green.

Benzoic acid exists in gum benzoin. It is benzol in which one hydrogen atom is replaced by the radical COOH. It is a crystalline solid, possessing a very fragrant odor.

Hippuric acid exists in the urine of cattle. It occurs in slender, milky-white crystals.

Salicyl hydride is the essential oil of meadow-sweet, and is isomeric in composition with benzoic acid.

Salicylic acid occurs naturally in oil of meadow-sweet and winter-green. It possesses in a remarkable degree the properties of an antiseptic, for which purpose it is better suited than carbolic acid, since, unlike this substance, it has no smell.

Anisic acid, and anisic aldehyde, occur in oil of anise and fennel.

Gallic acid is obtained by the gradual oxidation of moistened nut-galls.

Digallic acid, or tannin, or tannic acid, is extracted from nut-galls by ordinary ether. It is largely employed in the manufacture of ink.

The terpenes, or the essential oils, belong to the aromatic series. They include oil of turpentine, lemon, orange flower, peppermint, and cloves. They are all isomeric in composition, and change spontaneously into oil of turpentine.

Camphor is derived from the wood of the laurus camphora, by distilling it with water.

Naphthalene contains condensed benzole nuclei, probably arranged in two closed chains. Naphthalene and anthracene are solid hydrocarbons derived from coal-tar. They form the basis for the formation of a magnificent series of coloring matters.

QUESTIONS FOR REVIEW.

Explain the nature of the grouping of the carbon atoms in the benzol or aromatic nucleus.

How may additive compounds be obtained from benzol? How may substitution compounds be obtained from benzol?

How may benzol be produced synthetically? Describe the properties of benzol. For what is it employed? How is it produced commercially?

How is nitro-benzol produced? What are its properties? For what is it used? What valuable compound is obtained from it?

What is the composition of carbolic acid? By what other names is it known? What relation does it sustain to benzol?

Describe the properties of carbolic acid. For what purposes is it used? How may its presence be detected?

What is the principal source of aniline? Describe its properties. For what is it used?

How may picric acid be obtained from phenol? By what other name is it known? For what purposes is it employed?

What is the principal source of commercial indigo? How is it obtained from this source?

Describe the method adopted for dyeing fabrics with indigo.

What is the source of quinone? What are its properties?

What is the source of toluol? What are its properties?

What chemical relations does the oil of bitter almonds sustain to toluol?

What is toluidine? In what important substance is it always present?

Describe the method by which rosaniline is generally prepared. What is necessary in order that rosaniline may develop its coloring properties?

Name some of the salts of rosaniline that are employed as coloring matters.

What chemical relations does benzoic acid sustain to benzol? From what source is benzoic acid generally obtained? What properties does it possess? What is the principal source of hippuric acid?

What chemical substance forms the essential oil of meadow-sweet?

How is salicylic acid generally prepared? What valuable properties does it possess?

Name the source of anisic acid.

How is gallic acid generally obtained?

How is digallic or tannic acid generally obtained? For what purpose is it largely employed?

Describe the natural sources of the terpenes or the essential oils. What are the general properties of this group?

What is the source of camphor? What curious experiment may be tried with camphor?

What is believed to be the peculiarity of the carbon nucleus in naphthalene?

Describe the uses of naphthalene and anthracene.

SECTION V.

SUBSTANCES OF UNCERTAIN CONSTITUTION.

CHAPTER VIII.

THE VEGETABLE ALKALOIDS AND THE ALBUMINOIDS.

483. Description of the Group.—Numerous substances that have been obtained from various organic products, both vegetable and animal, although well defined, are not yet sufficiently understood to enable us to determine their exact chemical constitution. This class must necessarily include widely differing substances, and must of course grow constantly smaller as chemical investigation advances. Among the many substances belonging to this class we will describe but a few of the more important.

484. The Natural Alkaloids.—These are among the most important of the vegetable derivatives. They exist in plants, and are alkaline bodies, compound ammonias, or amines, for the greater part of unknown constitution. They are basic, or alkaline to test-paper, and are capable of combining with acids to form definite crystallizable salts.

They exist in the plants combined with some organic acid, and are generally extracted from the plant by making an infusion of it in alcohol or water, and freeing the alkaloid from its natural acid by the addition of some alkali, such as lime. The free alkaloid is then extracted with alcohol, ether, or other solvent suitable to the particular case. Sometimes the alkaloid is insoluble in water, when it is precipitated by the lime, while the calcium salt itself is soluble, while at other times it remains in solution and an insoluble lime salt is precipitated. The process of extraction must of course be modified according to the character of the alkaloid. The number of the vegetable alkaloids is very great. We describe only some of the more important.

Conine, $C_8H_{15}N. = C_8H_{14}{=}NH$, is a colorless, extremely poisonous oil, that is obtained from the hemlock (*conium maculatum*). It is slightly soluble in cold water, and readily soluble in alcohol and ether. It has a powerful, disagreeable odor.

Nicotine, $C_{10}H_{14}N_2$, is the alkaloid of tobacco. It is a colorless, offensive liquid, with a powerful odor, and turns brown on exposure to the air. It is soluble in water and in alcohol, and is exceedingly poisonous.

Morphine, $C_{17}H_{19}NO_3+H_2O$, is the principal alkaloid of *opium*, the dried juice of the poppy. It crystallizes in small, colorless, rhombic prisms, slightly soluble in alcohol, but insoluble in water and ether. It has a bitter taste and is very poisonous. Its salts, especially the sulphate, are much employed in medicine as a narcotic. *Codeine*, *thebaine*, and *narcotine*, are some of the other alkaloids that exist in opium.

Quinine, $C_{20}H_{24}N_2O_2,3H_2O$, is one of the alkaloids that exist in cinchona bark, or Peruvian bark. The yellow and the red barks contain the most. Quinine is a white, crystalline powder. Its crystals are almost insoluble in water, but are readily soluble in alcohol, and have an intensely bitter taste. It is extensively used in medicine as quinine sulphate, which is soluble in hot water, and has a bitter taste. It is very soluble in hot water.

Cinchonine, $C_{20}H_{24}N_2O$, is also obtained from Peruvian bark. It resembles quinine, but is less soluble. It is not as valuable as a medicine as quinine.

Strychnine, $C_{21}H_{22}N_2O_2$, is an alkaloid obtained from a number of varieties of Strychnos, especially from the S. nux vomica. It crystallizes in colorless octahedra, that are almost insoluble in water, but are soluble in alcohol and ether. It has a bitter taste, and is frightfully poisonous. *Brucine* is another alkaloid obtained from S. nux vomica. It is less poisonous than strychnine.

Piperine, $C_{17}H_{19}NO_3$, is the alkaloid of pepper.

Atropine, $C_{17}H_{23}NO_3$, is the alkaloid of the deadly nightshade (*Atropa Belladonna*) and the *Solanum nigrum*. It has a bitter taste, and is very poisonous. It causes, even in small doses, a marked dilatation of the pupil of the eye.

Caffeine or Theine, $C_8H_{10}N_4O_2+H_2O$, exists in coffee and tea. It crystallizes in silky needles, that are not very soluble in cold water, but are quite soluble in hot water and in alcohol. It has a bitter taste, and is not very poisonous.

485. Protein Substances is a name applied to substances widely distributed throughout both the vegetable and animal kingdoms. These substances form the main part of the tissues in the animal body, from which fact they take their name. They all contain nitrogen in addition to the carbon, hydrogen, and oxygen, and in nearly all cases they contain sulphur also. None of the protein substances are crystalline. Their accurate formulæ are yet to be ascertained, but their molecules are undoubtedly very large, and complex. They comprise the albuminoid substances, the jellies, and the glues.

The inability of the colloids to pass through animal membrane as readily as the crystalloids, is probably due to the fact that their molecules are larger than the pores of the membranes.

Another proof of the complexity of their molecules is found in their ready decomposition during putrefaction, or by the action of heat in the presence of acids or alkalies. Tannic acid precipitates all the protein substances, and alcohol nearly all of them.

486. Gelatinous Tissues — Gelatines.—Gelatinous tissues occur only in animals. They swell slightly when steeped in water, but are not dissolved by it. By long boiling they are converted into *gelatines*, substances whose hot solutions set or become jellies on cooling.

There are two varieties of gelatine, viz., *chondrogen* and *collagen*. Chondrogen forms the main portion of the bones of very young animals. Collagen or glutine, is the variety of gelatine that when dried from its hot solution forms *glues*. The purest form of gelatine is obtained from the swimming-bladder of fishes. A form of liquid glue is produced by dissolving glue in acetic acid or vinegar. Ordinary leather consists mainly of tannic acid and glutine.

487. Albuminoid Substances.—The principal albuminoid substances are *albumen*, *fibrin*, *casein*, *myosin*, *hemoglobin*, and *globuline*. They are very complex substances, some of them having more than 600 atoms of carbon to every atom of sulphur. With the exception of albumen, they are insoluble in water, but are soluble in water containing a small quantity of acid. By the action of heat their insolubility is greatly increased. When dissolved in hydrochloric acid, they form a series of alkaline compounds called the *albuminates*.

Tannic acid precipitates the albuminoids in flocculent masses.

Strong nitric acid colors them a deep yellow. Concentrated hydrochloric acid dissolves them, the solution assuming a violet-blue on exposure to the air.

Albumen.—There are two modifications, viz., the soluble and the insoluble.

Soluble albumen exists in many of the animal liquids. It is best seen in the white of eggs. The coagulable principle of the blood, the *serin*, is analogous to albumen.

Albumen is coagulated, or sets, at a temperature of about 164° F.

Insoluble albumen is obtained by precipitating albumen by strong alcohol.

Sulphuric, nitric, and hydrochloric acids produce a dense white flocculent precipitate of albumen.

Fibrin.—When freshly-drawn blood coagulates, it separates into the red coagulum, or *clot*, and a yellowish liquid, called the *serum*. The clot consists of red corpuscles imprisoned in a network of an insoluble albuminoid, called *fibrin*. Fibrin does not actually exist in the blood of living animals, but is formed during coagulation from two soluble substances in the liquid blood. Fibrin dissolves in hydrochloric acid, and forms a solution that turns blue on exposure to the air.

Casein is the thick precipitate formed by the addition of an acid to milk. The curdling of milk so produced is due to the coagulation of an albuminoid matter, that is believed to be the same as albumen. The gastric juice coagulates the milk, both because it is acid and because it contains a ferment called *pepsin*, that exists in *rennet*, a substance prepared from one of the stomachs of a calf. Cheese consists of casein somewhat altered by putrefactive decay.

488. Vegetable Caseins.—*Legumin* is an alkaline albuminate, that exists in peas and beans. *Gluten casein* exists in flour, and in most all the cereals. It is insoluble in water and in alcohol.

Myosin is an albuminoid substance, that exists in solution in the sheaths of the muscular fibres. On the death of the animal this substance coagulates and produces the well-known rigor or stiffening.

Hemoglobin, unlike any of the preceding, is a crystalline substance. The form of the crystals differs with the kind of blood from which they have been derived. They are of a deep-red color. The true albuminoid principle here is probably globulin.

Globulin is a coagulable albuminoid, obtained from the red blood corpuscles. It is probably a decomposition product of hemoglobin. It is closely allied to albumen in its properties.

Besides the substances already mentioned, others occur in the various animal fluids. They are very complex in structure.

SYLLABUS.

Many of the substances derived from animals and vegetables are of uncertain chemical constitution. Such, for example, as the vegetable alkaloids, the glutens, gelatine, and the albuminoids.

The vegetable alkaloids are basic, alkaline substances, that combine with acids and form definite crystalline salts. They exist in plants as salts.

The vegetable alkaloids are extracted from plants by adding lime or some other alkali to an infusion of the plant in water or alcohol.

Conine is a very poisonous alkaloid obtained from the hemlock.

Nicotine is the alkaloid of tobacco. It is a colorless, offensive liquid, and is very poisonous.

Morphine is the principal alkaloid of opium. It crystallizes in colorless rhombic prisms. Its salts, especially the sulphate, are used in medicine as an opiate.

Codeine, thebaine, and nicotine are other alkaloids that exist in opium.

Quinine is a valuable alkaloid obtained from the Peruvian bark or cinchona tree. Quinine sulphate is extensively employed in medicines. Cinchonidine is another alkaloid that exists in Peruvian bark.

Strychnine is an alkaloid obtained from nux vomica. It is one of the most poisonous of the vegetable alkaloids.

Brucine is another poisonous alkaloid obtained from the nux vomica.

Piperine is obtained from pepper.

Atropine is obtained from the deadly nightshade. It is commonly known as belladonna.

Caffeine or theine are the alkaloids of coffee and tea.

The protein substances are those which form the main portions of the tissues of animals and plants. All the protein substances contain nitrogen in addition to the carbon, hydrogen, and oxygen, and nearly all contain sulphur. Their molecules are large and complex.

The protein substances comprise the albuminoids and the gelatinous substances.

The gelatinous substances include chondrogen and collagen. The albuminoids include albumen, fibrin, casein, myosin (hemoglobin), and globuline.

The albuminoid substances, with the exception of albumen, are all insoluble in water; they are soluble, however, in hydrochloric acid. They are all precipitated by tannic acid.

Albumen exists in two varieties, viz., the soluble and the insoluble. The first exists in the white of eggs. The second may be produced by the action of strong alcohol on soluble albumen. Albumen is coagulated by heat and by the action of sulphuric, nitric, and hydrochloric acids.

Fibrin is formed during the coagulation of blood. It holds the red corpuscles together to form the clot.

Casein is the coagulum or curd formed by the addition of an acid to milk. It forms the basis of cheese.

Legumin and gluten are vegetable caseines.

Hemoglobin is a coagulable substance derived from the blood. When blood coagulates, globulin, a true albuminoid, is produced.

* * *

QUESTIONS FOR REVIEW.

Name the principal sources of the substances whose exact chemical constitution is unknown.

Name the principal vegetable alkaloids. In what form do they exist in plants? How are they generally separated from plants?

What is the natural source of conine? Describe some of its properties.

What is the source of nicotine? Describe some of its properties.

Name some of the alkaloids that are derived from opium. Which is the most important of them?

What is opium?

In what form is morphine generally employed in medicine?

What two alkaloids are obtained from cinchona bark? Which of these is the more valuable for use in medicine? In what form is it generally employed?

From what source is strychnine generally obtained? What other alkaloid is obtained from the same source? Which is the more poisonous?

What alkaloid exists in pepper?

What is the source of atropine? What peculiar effect has atropine on the pupil of the eye?

Describe the principal characteristics of the protein substances.

What is the probable reason that the colloids are unable to pass through the pores of membranes as readily as crystalline substances?

Where do the gelatinous substances exist? Into what two varieties may these substances be divided?

What is glue? How is it obtained?

What is the composition of ordinary leather?

Name the principal albuminoid substances. Describe some of the general properties of these substances. How may the albuminoid substances be detected?

What two modifications of albumen exist? Name any natural source of albumen.

Does fibrin exist in the blood of live animals?

What is casein? How may it be obtained? Name some of the vegetable caseins.

What is myosin?

What is hemoglobin? Where does it exist? What is globulin?

QUESTIONS FOR EXAMINATION.

PART I.—THEORETICAL CHEMISTRY.

Chapter I.

Introductory.—The Nature of the Chemical Force.

1. Name the different species of attraction. To which of these does the chemical force belong?

2. Distinguish between cohesion and adhesion, and name some examples of each.

3. What is meant by a chemical change? By what is such a change caused?

4. Explain in full what you understand by the word molecule.

5. Define atom. Which is the larger, an atom or a molecule of a substance? Why?

6. Explain the difference between chemical affinity and molecular attraction.

7. Enumerate the circumstances that influence atomic or chemical combination.

8. By what different forces may the chemical decomposition of a substance be effected?

9. Why are some chemical compounds stable and others unstable?

10. Distinguish between analysis and synthesis.

Chapter II.—Theory of Chemical Combinations.—Definite and Multiple Proportions.—Atomicity and Quantivalence.

1. Explain in full what you understand by the term atomic weights.

2. Give a brief statement of the laws of definite proportions and multiple proportions.

3. What is meant by atomic symbols? Of what use are they in chemistry?

4. Write the atomic symbols for the following elements, viz., mercury, tin, oxygen, cæsium, iron, sulphur, molybdenum, selenium, phosphorus, and platinum.

5. Explain the use of the symbols and figures in the following equation, viz.:

$$4(H_2+O)=4H_2O.$$

6. Define atomicity; quantivalence. What different terms are used in order to distinguish the quantivalence of an element?

7. Distinguish between graphic and empiric chemical formulæ.

8. Define perissad elements; artiad elements; give five examples of each.

9. Explain why free hydrogen must be molecular.

10. Write the graphic formula for hydrogen silicide. Write its empiric formula.

Chapter III.

Theory of Substitution.—Chemical Nomenclature.

1. Why must the chemical molecule form a complete unit of chemical existence?

2. Explain in full what you understand by the term replacement or substitution as used in chemistry.

3. Define simple and compound radicals, and give an example of each.

4. What is meant by an acid? What properties does an acid possess? How is an acid formed?

5. What is meant by a base? What properties does a base possess? How is a base formed?

6. Write the graphic formula for any acid substance. Write the graphic formula for any basic substance.

7. Explain the manner in which salts are produced. Illustrate by means of a graphic formula.

8. Define hydracids; haloid salts.

9. What termination is generally given to the metals in their chemical nomenclature? How is this termination changed in binary compounds? Illustrate by examples.

10. Explain the use of the terminations *ous*, *ate*, and *ite*, and the prefixes *mon*, *di*, *tri*, *tetra*, and *pent* in chemical nomenclature.

Chapter IV.—Combination by Volume.—Gay Lussac's Laws. —Molecular Volume.

1. Why must gaseous elements combine by equal volumes, or by whole multiples of equal volumes?

2. State concisely the theorem of Avogadro.

3. Enumerate the circumstances that tend to establish the theorem of Avogadro.

4. When gaseous combination occurs by volume, to what is the volume of the resulting gaseous compound invariably equal?

5. Under what circumstances is the combination of elementary gaseous substances unattended by shrinkage of volume? When must such a shrinkage occur?

6. What facts have been discovered concerning the actual size of the molecule of air?

7. In what manner may the molecular weight of a gas or vapor be readily ascertained?

8. If the density of a gas or vapor be given as compared with air, how may its density as compared with hydrogen be readily ascertained? Why?

9. Define specific heat. In what condition have all substances the same specific heat?

10. Show by means of a diagram the effect produced by the union of four volumes of hydrogen with one volume of carbon.

* * *

Chapter V.—Crystallography.

1. Distinguish between a crystalline and an amorphous solid.

2. Why must the molecules of a substance be given freedom of motion in order that crystallization may readily occur?

3. Name all the circumstances that favor the crystallization of solids.

4. Define the following terms; viz., crystal, holohedral modification, hemihedral modification, axes of a crystal.

5. Describe the monometric system of crystals, and name the simple forms that belong to it.

6. Describe the dimetric system of crystals, and name the principal forms that belong to it.

7. Describe the trimetric system of crystals, and name the principal forms that belong to it.

8. Describe the monoclinic system of crystals, and name the principal forms that belong to it.

9. Describe the triclinic system of crystals, and name the simple form that belongs to it.

10. Describe the hexagonal system of crystals, and name the principal forms that belong to it.

PART II.—DESCRIPTIVE AND EXPERIMENTAL CHEMISTRY.

THE NON-METALS.

SECTION I.—HYDROGEN AND THE HALOIDS.

Chapter I.

Classification of the Non-Metallic Elements.—Hydrogen.

1. Under what four groups may all the non-metallic elements be arranged? What is the quantivalence of each of these groups?

2. Show by means of graphic formulæ the type of molecular structure produced by the union of a substance in each of these groups with hydrogen.

3. Under what circumstances does hydrogen occur free in nature? What is the principal source of hydrogen in combination?

4. Describe the apparatus employed in the production of hydrogen by the action of sulphuric acid on metallic zinc.

5. Write the chemical reaction that occurs in the preparation of hydrogen by the action of sulphuric acid on metallic zinc.

6. State the principal physical properties of hydrogen.

7. Explain in full what is meant by the occlusion of hydrogen.

8. State the more important chemical properties of hydrogen.

9. How may an explosion be caused by the combustion of hydrogen in air? Under what circumstances is such an explosion harmless? When is it dangerous?

10. Prove that water is the sole product of the combustion of hydrogen in air.

Chapter II.—Chlorine, Bromine, Iodine, and Fluorine.

1. Name the principal natural source of chlorine.

2. Write the reaction that occurs when hydrochloric acid is heated with the dioxide of manganese.

3. Describe the physical and chemical properties of chlorine.

4. What is the chemical composition of hydrochloric acid? In what manner may it be conveniently prepared?

5. Describe the physical and chemical properties of hydrochloric acid.

6. Write the reaction that occurs in the preparation of bromine by the action of sulphuric acid and manganese dioxide on potassium bromide.

7. What is the principal natural source of iodine? Explain the manner in which it is obtained from this source.

8. Describe the principal uses of bromine and iodine.

9. By what simple test may the presence of iodine be detected?

10. How is hydrofluoric acid prepared? For what is it employed? Write the chemical reaction that takes place during its preparation.

SECTION II.

OXYGEN, SULPHUR, SELENIUM, AND TELLURIUM.

Chapter III.

Oxygen, and its Compounds with the Preceding Elements.

1. Enumerate the principal natural sources of oxygen.

2. By what process may oxygen be most conveniently prepared for use in the laboratory? Write the reaction that occurs during its preparation by this process.

3. Describe the more important physical and chemical properties of oxygen.

4. By what means is water freed from foul organic impurities on exposure to the air?

5. What is ozone? Describe its properties. Under what circumstances is it produced?

6. Enumerate the principal varieties of mineral waters, and state the characteristic mineral ingredient in each variety.

7. Define water of crystallization; efflorescence; deliquescence.

8. Name the principal ingredients of the atmosphere, and state briefly the use of each.

9. Write empiric formulæ for the anhydrous and the hydrated oxides of chlorine, and give their chemical names.

10. Name the principal compounds of bromine and oxygen.

Chapter IV.—Sulphur, Selenium, and Tellurium.

1. Describe the method usually adopted for refining or purifying sulphur.

2. Describe the allotropic modifications of sulphur. How are each of these obtained?

3. What peculiarities are noticeable in sulphur during its liquefaction by heat?

4. What are the principal chemical properties of sulphur?

5. How is hydrogen sulphide most conveniently prepared? Describe its principal properties. For what is it mainly employed?

6. Write the chemical reaction that takes place during the preparation of sulphurous acid, by the action of heat on a mixture of metallic copper and sulphuric acid.

7. What is the principal use of sulphurous oxide in the arts? To what does the sulphurous oxide owe its bleaching powers?

8. Explain in full what is meant by the nascent state. Illustrate by examples.

9. What is the composition of sulphuric acid? Describe the process by which it is generally produced. What are its principal properties and uses?

10. Describe the sources and properties of selenium and tellurium.

SECTION III.—NITROGEN, PHOSPHORUS, BORON, ARSENIC, ANTIMONY, AND BISMUTH.

Chapter V.—Nitrogen.

1. By what means may nitrogen be obtained from the atmosphere?

2. What is the chemical composition of ammonia-gas? How is ammonia-gas most conveniently prepared? Write the chemical reaction that occurs in its preparation.

3. Describe the ammonium theory. Write the graphic formula for the compound radical ammonium.

4. Name and describe any three salts of ammonium.

5. Describe the preparation and properties of nitrogen monoxide or laughing-gas, and write the reaction that occurs in its preparation.

6. Describe the preparation and properties of nitrogen dioxide, and write the reaction that occurs in its preparation.

7. Describe the preparation and properties of nitric acid, and write the reaction that occurs in its preparation.

8. Explain the origin of the beds of natural nitrates found in various parts of the world.

9. What is aqua regia? How is it prepared?

10. Write the empiric formulæ for nitrogen trioxide and nitrogen tetroxide.

Chapter VI.

Phosphorus, Arsenic, Boron, Antimony, and Bismuth.

1. Name the principal natural sources of phosphorus.

2. Write the reactions that occur during the extraction of phosphorus from bones.

3. Describe the properties of phosphorus. What allotropic modifications are there?

4. In what respect is the density of phosphorus vapor anomalous?

5. Describe the preparation of spontaneously combustible hydrogen phosphide, and write the reaction that occurs during its preparation.

6. Write the empiric formulæ for hypophosphorous, phosphorous, and phosphoric acids.

7. Describe the preparation and properties of metallic boron. Write the empiric formula for borax.

8. Name the principal ores of arsenic. What are its principal compounds with oxygen? By what means may the presence of arsenic be detected?

9. Describe the properties of metallic antimony. What is the composition of type metal?

10. How is metallic bismuth obtained? What is the composition of pearl-white?

SECTION IV.—CARBON AND SILICON.

Chapter VII.—Carbon and Silicon.

1. What is the chemical composition of the diamond? Describe some of its properties.

2. In what two ways may artificial graphite be obtained?

3. Enumerate the different varieties of amorphous carbon.

4. Describe the chemical properties of carbon. What valuable chemical property does incandescent carbon possess?

5. How may carbon monoxide be prepared? What name is given to this substance when it acts as a compound radical?

6. Describe the method generally adopted for the preparation of carbonic acid gas, and write the reaction that takes place during its preparation.

7. How is carbon disulphide prepared? Describe its properties.

8. Explain in full the nature of the heat evolved during the combustion of coal in air.

9. Name some of the natural varieties of amorphous silicon dioxide.

10. Describe in full Graham's process of dialysis.

THE METALS.

SECTION I.—INTRODUCTORY.

Chapter VIII.

Properties and Classification of the Metals.

1. Enumerate the general properties that characterize the metals as a class.

2. Describe the process adopted for obtaining a ductile metal in the shape of a wire.

3. Name five metallic substances whose specific gravity is more than 10. Name five whose specific gravity is less than 10.

4. Define amalgam; alloy. What is the composition of the following alloys, viz.: white brass; gun-metal, and German silver?

5. What means are generally adopted for the reduction of metallic oxides? For the reduction of metallic sulphides?

6. Define conchoidal fracture; columnar fracture; fibrous fracture; crystalline fracture, and granular fracture.

7. Why is it more difficult to determine the exact quantivalence of the metals than of the non-metals?

8. What peculiarity exists concerning the temperature of fusibility of an alloy as compared with the fusibility of its constituent metals?

9. Into what two classes may all metals be divided?

10. Name the metals of the alkalies. Name the metals of the platinum group. What is the quantivalence of each of these groups?

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THE PERISSAD METALS.

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SECTION II.—THE MONAD METALS.

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Chapter IX.—The Metals of the Alkalies and Silver.

1. Describe the general characteristics of the metals of the alkalies.

2. Describe the process generally adopted for the preparation of metallic potassium, and write the reaction that takes place during the operation.

3. Describe the manufacture of gunpowder.

4. What is the chemical composition of common salt? What are its principal sources? Describe its preparation and properties.

5. Describe the Leblanc process for the manufacture of sodium carbonate.

6. What are the principal sources of lithium? How may the presence of lithium salts be detected?

7. Describe the general properties of cæsium and rubidium.

8. In what three ways may silver be extracted from its ores?

9. Explain the manner in which silver chloride is employed in obtaining a print from a photographic negative.

10. What is the antidote for silver nitrate?

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SECTION III.—THE TRIAD AND THE PENTAD METALS.

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Chapter X.

Gold and Thallium.—Vanadium, Columbium, and Tantalum.

1. Describe the general properties of gold. In what condition does this metal occur in nature?

2. What is meant by 18-carat gold? By 22-carat gold? Describe the cupellation process for assaying gold alloys.

3. Describe the process of cradling as employed for auriferous soils. Describe the amalgamation process.

4. Mention any fact that shows the extreme malleability of gold.

5. How is the trichloride of gold produced? What is the purple of Cassius?

6. How was thallium discovered? Describe its general properties. What is the origin of its name?

7. Describe the preparation and properties of metallic vanadium.

8. Name some characteristic tests for salts of gold.

9. Describe the preparation and properties of metallic tantalum.

10. Name the triad metals. Name the pentad metals.

THE ARTIAD METALS.

SECTION IV.—THE DYAD METALS.

Chapter XI.—Barium, Strontium, Calcium, and Lead.

1. Describe the general characteristics of the metals of the alkaline earths.

2. What are the principal natural sources of barium? Write the empiric formula for barium chloride.

3. Name the chemical ingredients of the red fire of the pyrotechnist.

4. Distinguish between mortars and cements. Explain the causes that produce the hardening of mortar.

5. How is calcium chloride prepared? What valuable property does it possess?

6. How is chlorinated lime prepared? For what purpose is it employed extensively in the arts?

7. Describe the process generally employed for the reduction of galena, and write the reactions that occur during this reduction.

8. Describe the properties and uses of metallic lead.

9. What is the chemical composition of litharge? of minium? For what purposes are these substances employed?

10. Describe in full the Dutch process for the manufacture of white lead.

Chapter XII.—The Metals of the Earths.

1. Show by means of a graphic formula that the quantivalence of an element is frequently different from its apparent quantivalence.

2. Enumerate the principal natural sources of aluminium.

3. Name some of the valuable properties that aluminium possesses. What is the composition of aluminium bronze?

4. Name the principal natural crystalline forms of aluminium oxide or alumina.

5. Describe the process adopted for the commercial manufacture of alum.

6. Name any five alums, and write their empiric formulæ.

7. Distinguish between china, porcelain, and stoneware. How are these substances usually glazed?

8. What is the principal mineral source of glucinum? From what is its name derived?

9. In what mineral substance are the rare earths, yttrium, erbium, terbium, lanthanum, and didymium found? Who discovered each of these elements?

10. What are the principal natural sources of thorium and cerium?

◆

Chapter XIII.—Magnesium, Zinc, and Cadmium.

1. Describe the characteristics of this group of metals.

2. Name the principal mineral sources of magnesium. How is magnesium obtained in the metallic state?

3. Write the empiric formulæ for the following substances, viz.: calcined magnesia, magnesium sulphate, and magnesium carbonate.

4. Describe the principal characteristics of the salts of magnesium.

5. Name the principal ores of zinc.

6. Describe the method of extracting zinc known as the "distillation per descendum."

7. Describe the properties of metallic zinc. What is meant by galvanized iron?

8. By what tests may the salts of zinc be detected?

9. How is metallic cadmium prepared? Describe its properties.

10. Name the principal compounds of cadmium.

Chapter XIV.—Mercury and Copper.

1. In what respects do mercury and copper resemble each other?

2. Explain the process adopted at Idria for the extraction of mercury from cinnabar.

3. What valuable properties are possessed by metallic mercury? For what different purposes is it employed?

4. How is blue-mass prepared? What effect has mercury on the human system when taken for a long time in small doses?

5. Distinguish between corrosive sublimate and calomel.

6. By what characteristic tests may the salts of mercury be detected?

7. Describe the process usually adopted for the extraction of copper from its ores.

8. State the properties and uses of metallic copper.

9. Write the empiric formulæ for the following substances, viz.: red oxide of mercury, cinnabar, mercuric sulphate, malachite, and copper sulphate.

10. Give the tests for the salts of copper.

SECTION V.—THE TETRAD METALS.

Chapter XV.—The Metals of the Platinum Group.

1. Name the metals of this group and state their general characteristics.

2. With what metallic substance is platinum generally associated?

3. What valuable properties possessed by platinum fit it for use in the laboratory? What is platinum black?

4. Why is metallic palladium preferable to other metals when used for the delicate graduated scales of mathematical instruments?

5. Describe the properties of metallic iridium.

6. By what tests may the presence of salts of platinum be detected?

7. In what form does rhodium occur in nature? What are the properties of metallic rhodium?

8. What peculiarity is possessed by ruthenious chloride?

9. Explain the nature of the danger attending the volatilization of metallic osmium.

10. Which of the metals of the platinum group are especially noted for their power of occluding hydrogen?

Chapter XVI.—Tin and Titanium.

1. In what respects do tin and titanium resemble each other?

2. Describe the occurrence and metallurgy of tin.

3. What are the characteristic properties of metallic tin? For what purposes is metallic tin employed in the arts?

4. What is the composition of phosphor-bronze? What valuable properties are possessed by this alloy?

5. What do you understand by the liquation of tin?

6. Explain the manner in which a looking-glass may be prepared by the use of mercury and tinfoil.

7. By what characteristic tests may the salts of tin be recognized?

8. Write empiric formulæ for the following substances, viz.: stannic chloride, stannous chloride, mosaic gold, cassiterite, and rutile.

9. Name the principal mineral sources of titanium.

10. Why cannot metallic titanium be prepared by the ordinary metallurgical processes?

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SECTION VI.—THE HEXAD METALS.

Chapter XVII.—The Metals of the Iron Group.

1. What are the characteristics of the metals of the iron group?

2. Name the more important of the ores of iron.

3. Explain in full the manner in which the ores are reduced in the blast-furnace.

4. Describe the Bessemer process for the manufacture of steel.

5. How is cast-iron converted into wrought-iron?

6. By what characteristic tests may the salts of iron be recognized?

7. What is the empiric formula for potassium permanganate? What valuable properties does this substance possess?

8. Describe the tests by means of which the salts of cobalt may be detected.

9. Write the empiric formula for ammonium nickel sulphate. For what purpose is this substance extensively employed in the arts?

10. Describe the principal properties of iridium and gallium. How were these rare metals discovered?

Chapter XVIII.—The Metals of the Chromium Group.

1. In what respects do the metals of this group resemble one another?

2. Give the names and properties of the compounds of chromium and oxygen.

3. How is potassium dichromate prepared commercially? What are its properties? For what purposes is it employed in the arts?

4. State the characteristics of the salts of chromium.

5. What are the principal mineral sources of chromium?

6. Write empiric formulæ for chrome-green, chrome-yellow, chrome-ochre, and chrome-red.

7. Name the principal mineral sources of molybdenum.

8. With what mineral substances is tungsten or wolframium usually associated?

9. State the composition of the compound radical uranyl. Name some of the compounds it forms.

10. Which of the metals of the chromium group form anomalous chlorides? In what respects are these chlorides anomalous?

PART III.—ORGANIC CHEMISTRY.

SECTION I.—PRELIMINARY PRINCIPLES.

Chapter I.—Introductory.

1. Explain briefly the scope of organic chemistry. What is meant by the immediate principles of an organic compound?

2. Describe Liebig's process for the determination of the carbon and the hydrogen of an organic compound.

3. Explain the method generally adopted for the determination of the nitrogen.

4. By what means are the molecular formulæ of organic substances ascertained?

5. Prove by means of graphic formulæ that the valency of a carbon nucleus depends on the manner in which the carbon atoms are grouped.

6. Explain in full the theory of replacement or substitution.

7. Distinguish between empirical and rational formulæ.

8. Define isomerism. What two varieties of isomerism are there?

9. Define homologous series; destructive distillation; putrefaction; decay, and fermentation.

10. Under what four general classes may all organic compounds be arranged?

SECTION II.—SINGLE-LINKED CARBON NUCLEI.

Chapter II.—Cyanogen; its Compounds and Derivatives.

1. Show by means of a graphic formula the derivation of the compound radical cyanogen. What is the composition of gaseous cyanogen?

2. By what means may cyanogen be prepared? What are its properties?

3. What is the composition of prussic acid? How is it prepared? What are its properties?

4. By what tests may the presence of hydrocyanic or prussic acid be detected?

5. How is potassium cyanide prepared? What are its principal uses in the arts?

6. Explain the origin of the compound radical ferrocyanogen? What is its quantivalence?

7. Describe the process for the manufacture of potassium ferrocyanide, or the yellow prussiate of potash. For what purposes is it employed?

8. How is potassium ferricyanide prepared? How does it differ in its properties from potassium ferrocyanide?

9. Describe the preparation and properties of potassium sulphocyanate, or potassium sulphocyanide.

10. What is the composition of urea? In what respects is it related to the cyanogen compounds?

Chapter III.—Single-Linked Carbon Nuclei.—The Paraffines, or the Marsh-Gas Series.

1. Write a homologous series of the paraffines up to C_{10}.

2. Describe the general properties of methane. How may it be prepared from sodium acetate? Write the reaction that occurs during its preparation.

3. Distinguish between cymogene, rhigolene, gasoline, naphtha, and benzine.

4. Explain what is meant by fractional distillation. Describe the apparatus employed.

5. Name the alcohol radicals. How are the alcohols derived from these radicals?

6. Describe the general properties of ethylic or ordinary alcohol.

7. Describe the general process for the manufacture of beer.

8. How are the ethers derived from the alcohols? How is ordinary ether obtained? What are its properties?

9. By what means are the mercaptans or the thio-alcohols produced? What are their properties?

10. How are the phosphines and the arsines derived? What are their general properties?

Chapter IV.—Single-Linked Carbon Nuclei (Continued).—Derivatives of the Dyad Paraffine Radicals.

1. Write graphic formulæ of the dyad paraffine radicals up to C_4.

2. How are the aldehydes derived from these radicals? How are the glycols or diacid alcohols derived from them?

3. What is the origin of the word aldehyde?

4. Show by means of a chemical formula the derivation of ordinary aldehyde by the oxidation of ethyl alcohol.

5. What are the properties of ordinary aldehyde?

6. How is chloral produced? What valuable properties does this substance possess?

7. What are ketones or acetones? How are they obtained?

8. Write the graphic formula for ethylene glycol. What other glycols are there?

9. How is lactic acid produced? In what source does this acid exist naturally?

10. Write the graphic formula for the compound radical ethylidene.

Chapter V.—The Single-Linked Carbon Nuclei (Continued).—The Trivalent Paraffine Radicals.

1. Write graphic formulæ for the trivalent paraffine radicals up to C_4.

2. How is chloroform or formyl trichloride produced? What are its properties? Write its graphic formula.

3. Write graphic formulæ for the univalent acid radicals called the acidoxyls up to C_4.

4. What is the nature of the acetic fermentation? Describe the quick process for the manufacture of vinegar.

5. What is the chemical composition of the following artificial flavors, viz.: Jargonelle pear; pineapples, and apples?

6. Write the graphic formula for the compound radical glyceryl. How is glycerine derived from this radical? What are the properties of glycerine?

7. How are soaps produced? To what does soap owe its cleansing properties?

8. What is the composition of trinitroglycerine? Of gun-cotton? How are they produced? What are their properties?

9. Describe the general properties of glucose and saccharose. What is the composition of molasses?

10. How is oxalic acid produced? What are its properties? What is its antidote?

SECTION III.

THE DOUBLE- AND TRIPLE-LINKED CARBON NUCLEI.

Chapter VI.—The Double- and Triple-Linked Carbon Nuclei.

1. Describe the characteristics of this group.

2. What is the general formulæ of the olefines?

3. Why must the olefines be diatomic? What is the origin of the name?

4. Write the graphic formula for ethylene.

5. How is ethylene produced? What are its properties? By what other names is it known?

6. Write the graphic formula for propylene. What are its properties?

7. Write the graphic formula for the compound radical allyl.

8. How is oil of garlic derived from allyl? How is oil of mustard derived from allyl?

9. Write the graphic formula for acetylene.

10. How is the synthesis of acetylene effected? What are the properties of acetylene?

SECTION IV.—THE CLOSED-CHAIN CARBON NUCLEI.

Chapter VII.—The Aromatic Compounds.

1. Explain the origin of the name "aromatic compounds."

2. Write the graphic formula for the benzol, or aromatic nucleus.

3. Why must the derivatives of benzol be additive compounds?

4. How may the synthesis of benzol be effected?

5. Describe the derivation of nitro-benzol. What are its properties?

6. How is carbolic acid produced? What are its properties? What is its chemical composition?

7. Explain the manner in which indigo is employed for the dyeing of fabrics.

8. How is rosaniline prepared? Name some of the more important dyes that are obtained from rosaniline.

9. What valuable property is possessed by salicyl hydride?

10. How is di-gallic acid or tannin obtained from nut-galls? Describe its use in the manufacture of ink.

SECTION V.

SUBSTANCES OF UNCERTAIN CONSTITUTION.

Chapter VIII.—The Alkaloids, and the Albuminoids.

1. In what form do the vegetable alkaloids occur in plants? What means are employed in order to obtain them in a state of purity?

2. Name the alkaloids that are obtained from opium. Which of these is extensively employed in medicine?

3. What is the principal natural source of quinine? In what form is it principally employed in medicine?

4. What is the source of strychnine? Describe its properties.

5. What alkaloid is obtained from the deadly nightshade? From tea? From coffee?

6. Explain the use of the term protein substances.

7. What consideration can you deduce to show the probable complexity of the molecules of the protein substances?

8. Name the two varieties of gelatine. How is glue formed?

9. Name the principal albuminoid substances. Explain the cause of the clotting or coagulation of freshly-drawn blood.

10. What is the cause of the stiffening or rigor of the muscles of an animal shortly after its death?

INDEX

A

PAGE

Absolute alcohol ... 338
Absorption, remarkable, of ammonia gas ... 120
Absorptive powers of charcoal ... 155
Acetal ... 353
Acetamide ... 362
Acetic acid ... 360
  acid, glacial ... 360
  aldehyde ... 352
  anhydride ... 362
  fermentation ... 360
Acetone or ketone ... 337, 350, 354
Acetylene ... 384
Achromatic lenses, how formed ... 170
Acid, anisic ... 395
  arachidic ... 359
  arsenic ... 140
  arsenious ... 139
  behenic ... 359
  benzoic ... 393
  boric ... 137
  bromic ... 99
  butyric ... 363
  capric ... 364
  caproic ... 363
  caprylic ... 364
  carbolic ... 390
  carbonic ... 159
  cerotic ... 359, 364
  chloric ... 99
  chlorocarbonic ... 331
  chlorochromic ... 304
  citric ... 370
  cyanic ... 330
  formic ... 359
  gallic ... 395
  glycolic ... 355
  hippuric ... 394
  hyænasic ... 359

PAGE

Acid, hydrobromic ... 80
  hydrochloric ... 78
  hydrocyanic ... 327
  hydroferricyanic ... 330
  hydroferrocyanic ... 328
  hydrofluoric ... 82
  hydrofluoric, properties of ... 83
  hypobromous ... 99
  hypochlorous ... 98
  hypophosphorous ... 134
  lactic ... 356
  lauric ... 359
  lignoceric ... 359
  malic ... 370
  manganic ... 290
  margaric ... 364
  medullic ... 359
  melissic ... 359
  metaphosphoric ... 136
  metatungstic ... 305
  myristic ... 359
  nitric ... 127
  nondecalytic ... 359
  œnanthylic ... 363
  oleic ... 384
  orthophosphoric ... 136
  oxalic ... 369
  -oxyls ... 385
  palmitic ... 364
  pelargonic ... 364
  pentadecylic ... 359
  perbromic ... 79
  phosphoric ... 135
  phosphorous ... 135
  picric ... 391
  propionic ... 362
  prussic ... 327
  salicylic ... 395
  silicic ... 168
  stannic ... 275

36 *

PAGE
Acid, stearic 364
  succinic 370
  sulphurous 108
  sulphuric 111
  tartaric 370
  telluric 115
  tellurous 115
  tridecylic 359
  tungstic 305
  undecylic 359
  uric 371
  valeric 363
Acids, definitions of 41
  fatty, how formed 358
  fatty, series of 358, 359
  nomenclature of 43
  organic 318
Acidulous water 94
Acrolein 352
Acrylic aldehyde 352
Additive compounds of benzol 388
Adhesion 16
Affinity, or chemical attraction 16
Agate 168
Air slaking of lime 217
Albite 234
  crystalline form of 63
Albumen 403
  detection of 403
  insoluble 403
  soluble 403
Albuminates 403
Albuminoid substances 403
Alcohol, absolute 338
  amylic 336
  amylic, in fusel oil 338
  benzyl 392
  dehydrogenatum 351
  ethylic 338
  how formed 318
  methylic 337
  radicals 336
  secondary propylic 337
  tertiary butylic 337
Alcohols, diacid or glycols 354
  primary 337
  radicals, oxides of 339
  secondary 337
  series of 318, 336
Aldehyde, acetic 352
  butylic 352

PAGE
Aldehyde, ethylic 352
  meaning of name 351
  methylic 351
  œnanthic 353
  palmitic 353
  radicals 353
  stearic 353
Aldehydes 337
Algaroth, powder of 142
Alkaline earths, metals of 211
Alkalies, metals of 183
Alkaloids, the vegetable 400
  vegetable, how obtained 400
Alkarsin 344
Allotropic modification, definition of 105
  modifications of carbon 150
  modifications of phosphorus 132
  modifications of sulphur 105
Alloys 177
  of aluminium 231
  of gold 205
Allyl 366
  or glyceryl 357
  sulphocyanate 384
  the radical 384
Alum 233
  burnt 233
  -cake 233
  concentrated 233
  varieties of 234
Alumina 231
Aluminium, alloys of 231
  bromide 232
  bronze 178, 231
  chloride 232
  fluoride 232
  iodide 232
  metallic, uses of 231
  occurrence and preparation 231
  oxide 231
  salts, characteristics of 235
  silicates 234
  sulphate 232
Amalgamation, process for extraction of silver 116
Amalgams 178
Amine, the radical 318
Amines or compound ammonias 343
Ammonia 119
  gas, experiment with 120

PAGE
Ammonia gas, how collected 119
preparation of 119
properties of 119
Ammoniacal copper sulphate 260
Ammonias, compound 343
Ammonium, acetate 362
alum 234
amalgam 121
carbonate 122
chloride 122
cyanate 331
hydrate 120
nickel sulphate 294
nitrate 122
sulphate 122
sulphydrate 122
theory 121
the radical 199
Amorphous carbon 152
silica 168
solid 55
Amyl acetate 365
bromide 336
chloride 336
hydrate 336
iodide 336
the radical 317
valerate 365
Amylene 383
Anæsthetic properties of laughing gas 124
Analysis, chemical 30
definition of 20
proximate 21
qualitative 21
quantitative 21
ultimate 21
ultimate, of organic compounds 311
Anatase 276
Anglesite 224
Anhydrite 220
Anhydrous acetic acid 362
Aniline 390
dyes 393
properties and uses of 390
Animal charcoal 154
Anisic acid 395
aldehyde 395
Annealing of steel 287
Anomalous density of arsenic vapor 132

PAGE
Anomalous density of phosphoric vapor 137
molybdenum chloride 305
tungsten chloride 305
uranium chloride 306
Anthracene 396
Anthracite coal 155
Antidote for arsenic 140
for nitrate of silver 198
for oxalic acid 369
Antimonic oxide 143
sulphide 143
Antimonio-potassium tartrate 370
Antimonous oxide 143
sulphide 143
Antimony 141
butter of 142
experiment with 142
extraction of 141
occurrence and preparation 141
penta-chloride 143
rings 142
tri-chloride 142
use in type metal 142
Antiseptic properties of carbolic acid 390
properties of formic acid 360
properties of salicyl hydride 394
Aqua ammonia 120
regia 129
Aqueous vapor in atmosphere, use of 97
Arbor Dianæ 198
Argillaceous iron ore 282
Argol 370
Aromatic compounds 387
or benzol nucleus 387
series of carbon compounds 322
Arsenic 137
acid 140
disulphide 140
extraction of 138
occurrence in nature 137
pentasulphide 141
properties of 138
rings 139
salts, characteristics of 140
terbromide 139
terchloride 139
terfluoride 139
teriodide 139

PAGE
Arsenic trisulphide 141
Arsenious acid 139
  oxide 139
Artiad elements, table of 34
  metals, classification of 180
Artificial apple flavor 365
  graphite 152
  Jargonelle pear flavor 365
  madder dyes 396
  pine-apple flavor 365
Assaying of gold 205
  of silver 196
  of silver, dry assay 196
  of silver, wet assay 196
Atmosphere, composition of 96
  effect of, on climate 97
  uses of ingredients of 96
Atomic attraction 16
  attraction, variable intensity of 17
  and molecular attraction, distinction between 17
  combination, circumstances influencing 18
  grouping in molecule, or atomic capacity 30
  symbols 27
  symbols, table of 29
  weights, definition of 25
  weights, table of 29
Atomicity 30
  representation of 31
Atoms and molecules, positions of 16
  and molecules, size of 16
  definition and general views of 15
Atropene 402
Attraction, atomic 16
  molecular 16
Auric chloride 204
Avogadro, theorem of 49
Azurite 256

B

Balsam of Tolu 392
Barium 212
  carbonate 214
  chloride 213
  cyanide 328
  dioxide 212
  green fire 214
  luminous paint 213
  metallic properties 212

PAGE
Barium, monosulphide 212
  monoxide 212
  nitrate 214
  origin of name 213
  principal source of 212
  rat poison 214
  salts, characteristics of 214
  sulphate 213
  sulphate, uses of 213
Baryta water 212
Bases, definition of 41
  mono, di-, or tri-acid 94
  nomenclature of 44
Basic lead chromate 303
Beer, how made 339
Belladonna 402
Bell metal 178
Benzine 335
Benzoic acid 394
  acid, derivative from hippuric acid 394
Benzol 387, 389
  additive compounds 388
  alcohol 392
  meta-derivatives 389
  ortho-derivatives 388
  para-derivatives 389
  substitution compounds 388
Berthollet's fulminating silver 198
Beryl 234
Beryllium or glucinum 235
Bichromate of potash 303
Binary compounds, definition of 42
Bismuth 143
  compounds, characteristics of 144
  experiment with 144
  fusible alloy of 145
  nitrate 144
  occurrence and extraction of 143
  properties and uses of 144
  tri-chloride 144
Bitter almonds, oil of 392
Bituminous coal 155
Black ink, how formed 289
  oxide of manganese 290
Blast-furnace process 283
Bleacher, sulphurous oxide as a 110
Bleaching, chlorine as an agent for 77
  powder 220
Blood charcoal 154
Blooms, iron 285

PAGE

- ***Blow-pipe,*** oxyhydrogen 95
- ***Blue*** litmus paper, use of 79
  - mass 253
  - vitriol 259
- ***Boiler*** scale 94
  - scale, formation of 220
- ***Bonds,*** definition of 32
  - influence of, in substitution 39
- ***Bone-black*** 154
  - experiment with 156
- ***Bones,*** important source of phosphorus 130
- ***Boracite*** crystalline, form of 59
- ***Borax*** 192
- ***Boric*** acid, commercial source of 137
- ***Borneo*** camphor 396
- ***Boron*** 136
  - compounds of, with the haloids 137
  - preparation and properties of 136
  - trioxide 137
- ***Boshes,*** of blast-furnace 283
- ***Brass,*** red 178
  - white 178
- ***Bricks,*** composition of 235
- ***Brimstone*** 103
- ***Brines,*** waters 94
- ***Britannia*** metal 178
- ***Brittleness*** of metals 175
- ***Bromic*** acid 99
- ***Bromine*** 79
  - derivation of name of 80
  - occurrence of 79
  - preparation of 79
  - properties of 80
- ***Bromoform*** 358
- ***Bronze,*** phosphor 274
- ***Brookite*** 276
- ***Brown*** hæmatite 282
- ***Brucine*** 402
- ***Brunswick*** green 259
- ***Bunsen*** burner, description of 88
- ***Burnt*** alum 233
- ***Butter*** of antimony 142
  - of tin 276
- ***Butyl*** hydrate 336
  - iodide 318
  - the radical 317
- ***Butylene*** 383
- ***Butylic*** alcohol 336
  - aldehyde 352
- ***Butyric*** acid 363

C

PAGE

- ***Cæsium*** 194
  - alum 234
  - sources and properties of 194
- ***Cacodyl*** 344
- ***Cacodylic*** oxide 344
- ***Cadmies*** 249
- ***Cadmium*** 249
  - characteristics of salt of 250
  - chloride 249
  - hydrate 249
  - iodide 249
  - oxide 249
  - sulphate 250
  - sulphide 249
- ***Caffeine*** 402
- ***Caking*** coal 155
- ***Calamine*** 245
- ***Calcareous*** waters 94
- ***Calcined*** magnesia 244
- ***Calcium*** 216
  - carbonate 219
  - chloride 218
  - chloride fused 218
  - cyanide 328
  - fluoride 219
  - hydrate 217
  - luminous paint 219
  - metallic preparation of 216
  - nitrate 221
  - oxide 217
  - phosphide, a source of phosphoretted hydrogen 130
  - properties of 216
  - proto-sulphide 219
  - salts, characteristics of 220
  - sources of 216
  - sulphate 220
  - thio-sulphate, crystalline form of 63
- ***Calcspar,*** crystalline forms of 64
- ***Calculi,*** urinary 371
- ***Calomel*** 253
- ***Camphor*** 396
- ***Candle-flame,*** hollow 163
- ***Cane*** sugar 372
- ***Capacity*** of atoms for combining, variable 30
- ***Capric*** acid 364
- ***Caproic*** acid 363
- ***Caprylic*** acid 364
- ***Carbohydrates,*** group of 371

PAGE

- ***Carbolic*** acid, properties of 390
  - test for 390
- ***Carbon*** 150
  - allotropic modifications of 150
  - chemical properties of 155
  - compounds, classification of 321
  - dioxide 157
  - dioxide, natural distribution of 158
  - dioxide, preparation of 158
  - dioxide, properties of 159
  - disulphide 156
  - monoxide 156
  - monoxide, preparation and properties of 156
  - nuclei, closed-chain 322
  - nuclei, double-linked 321
  - nuclei, double- and triple-linked. 382
  - nuclei, single-linked 321
- ***Carbonic*** acid, experiment with 159
  - acid in atmosphere, use of 97
  - acid in breath, detection of 97
- ***Carbonyl*** chloride 157
  - oxide 157
  - the radical 157
- ***Carboxyl,*** the radical 318, 331
- ***Caseine*** 403, 404
  - vegetable 404
- ***Cassiterite*** 273
- ***Cassius,*** purple of 276
- ***Catalan*** iron process 282
- ***Caustic*** soda 189
  - potash 186
- ***Celestine*** 214
- ***Cellulose*** 374
- ***Cements*** 218
- ***Cerite*** 238
- ***Cerium*** 238
  - oxide 238
- ***Cerotic*** acid 364
- ***Cerusite*** 224
- ***Cetylic*** palmitate 365
- ***Chalcedony*** 169
- ***Chalybeate*** waters 94
- ***Chameleon*** mineral 290
- ***Champagnes,*** how made 339
- ***Changes,*** chemical 13
  - physical 13
- ***Charcoal,*** absorptive powers of 155
  - animal 154
  - blood 154
  - wood 154

PAGE

- ***Cheese*** 404
- ***Chemical*** molecule 30
  - molecule, an entity 38
- ***Chemistry,*** definition of 14
- ***China*** 235
- ***Chloral*** 352
- ***Chloride*** of calcium tube 313
- ***Chlorinated*** lime 220
- ***Chlorine*** 75
  - as a supporter of combustion 77
  - chemical properties of 76
  - disinfectant and bleaching properties of 77
  - occurrence in nature 75
  - preparation of 75
  - physical properties of 76
- ***Chlorocarbonic*** acid 331
- ***Chlorochromic*** acid 304
  - anhydride 304
- ***Chloroform*** 357
  - properties and uses of 358
- ***Chlorous*** oxide 98
- ***Chondrogen*** 403
- ***Chrome*** green 302
  - iron ore 301
  - ochre 302
  - red 303
  - yellow 224
- ***Chromic*** chloride 304
  - hydrate 302
  - oxide 302
- ***Chromium*** 301
  - alum 234
  - anhydride 302
  - monoxide 302
  - oxychloride 304
  - salts, characteristics of 304
  - sesquioxide 302
  - trioxide 302
- ***Chromous*** chloride 303
- ***Cinchonine*** 401
- ***Cinnabar*** 251
- ***Clay,*** composition of 234
  - formation of 231
- ***Cleavage,*** definition of 65
- ***Coal,*** anthracite 155
  - bituminous 155
  - caking 155
  - non-caking 155
  - oil 334
  - semi-bituminous 155

PAGE

Cobalt 291
  chloride 292
  glance 291
  monoxide 292
  nitrate 293
  ores of 291
  salts, characteristics of 293
  sensitive ink 292
  sesquioxide 292
  sulphate 293
Cobaltous oxide 292
Codeine 401
Cohesion, acts in opposition to atomic attraction 18
  definition of 16
Coke, how made 154
Cold-short iron 285
Collogen 403
Colloids and crystalloids 169
Columbium 207
  occurrence and properties of 208
Columnar fracture 179
Combination by volume, laws of 48
Combining capacity of atoms 30
Combustion, influence of cohesion on 162
  nature of 161
  rapid, by oxygen 90
  slow, by oxygen 90
  tube 312
Complexity of molecule of protein substances 402
Composition of definite substance, invariable 24
Compound blow-pipe 95
  ethers, general properties of 365
Compounds, stable 18
  unstable 18
Conchoidal fracture 179
Conduction, influence of, on flame 164
Cones in candle-flame 163
Conine 401
Converter, for Bessemer steel process 286
Copper 256
  arsenite 260
  acetate, crystalline form of 60
  acetate, dibasic 362
  acetate, neutral 362
  carbonates, natural 260
  crystalline form of 59

PAGE

Copper, gray, crystalline form of 59
  salts, characteristics of 260
  sulphate, crystalline form of 63
  wet extraction process 257
Copperas 288
Corrosive sublimate 254
Corundum 232
Cream of tartar 370
Crocoisite 301
Crystalline forms, acute square octahedron 60
  forms, compound 56
  forms, oblique rectangular prism 62
  forms, oblique rhombic octahedron 62
  forms, oblique rhomboidal prism 62
  forms, obtuse square octahedron 60
  forms, regular octahedron 58
  forms, rhombic dodecahedron 58
  forms, rhombic octahedron 61
  forms, rhombic prism 61
  forms, rhombohedron 63
  forms, simple 56
  fracture 175
  solid 55
Crystallization, conditions favorable to 55
  water of 95
Crystallography 59
  systems of 57
Crystalloids and colloids 169
Crystals, dissimilar, definitions of 56
  modifications of 56
  similar, definition of 56
  twin, definition of 65
Cupel 195
Cupellation process 195
Cupric chloride 259
  nitrate 260
  oxide 258
  sulphate 260
  sulphide 259
Cuprite 258
Cuprous chloride 259
  oxide 258
  sulphide 259
Cyamelide 330
Cyanates 330
Cyanides, metallic 328
Cyanic acid 330
Cyanogen 326

PAGE
Cyanogen, bromide ... 330
chlorides ... 330
free ... 326
how formed ... 326
iodide ... 330
properties of ... 327
the radical ... 326
Cyanuric acid ... 332
Cymogene ... 334

D

Davy, discovery of metals of the alkalies ... 183
safety-lamp, construction of ... 165
safety-lamp, principle of ... 164
Decay ... 521
Decomposition of substance by heat ... 19
Deflagrating spoon, description of 90
Deliquescence of salts ... 95
Delivery-tube, description and use of ... 70
Deoxidizing cone of a candle-flame ... 164
Destructive distillation ... 320
Dextrin ... 374
Diallyl sulphide ... 384
Dialyser, Graham's ... 169
Dialysis, process of ... 169
Diamines ... 356
Diamond ... 150
composition of ... 150
crystalline forms of ... 151
valuable properties of ... 151
Diarsentetramethyl or cacodyl ... 344
Diastase, a peculiar ferment ... 339
use of ... 374
Diatomic ammonias ... 356
Dibromo benzol ... 389
Didymium ... 239
oxide ... 239
Diethylic glycol ... 356
Digallic acid or tannin ... 395
Dimetric system of crystals ... 59
Dimethyl aniline ... 393
phosphine ... 344
Dimethylmethane ... 336
Dimethylpropylmethane ... 336
Dimorphic forms of calculi ... 219

PAGE
Dimorphism, definition of ... 64
of sulphur ... 105
Disinfectant, chlorine as a ... 77
Distillation, destructive ... 320
dry ... 320
fractional ... 327
per descendum of zinc ... 246
process of ... 94
Dolomite ... 243
Dry distillation ... 320
lime purifiers, of illuminating gas 166
Drying oils, how they act ... 369
Ductility of metals ... 176
Dutch, white-lead process ... 224
Dyad element, definition of ... 31
paraffine radicals ... 350
Dyadic molecular type, non-metallic elements ... 69
Dynamite ... 368

E

"***Earth,***" original chemical significance of term ... 211
Earthenware ... 235
Efflorescence of salts ... 95
Electric light carbons, manufacture of ... 53
Electricity, influence of, on affinity ... 20
Elements, artiad ... 32
artiad, table of ... 34
molecular condition of ... 33
non-metallic, classification of ... 68
perissad ... 32
perissad, table of ... 33
Emery ... 232
Empiric formulæ ... 32
Empirical formulæ ... 319
Energy of combination ... 161
kinetic ... 161
potential ... 161
Epsom salts ... 244
Equations, chemical ... 28
Erbium ... 237
Essential oils ... 395
Etching on glass, use of hydrofluoric acid for ... 83
Ethane ... 334
Ether, methylic ... 340
ordinary properties and uses of ... 341

PAGE

- ***Ether,*** ethylic 340
- ***Ethereal*** salts 342
- ***Ethers*** 339
  - compound 342
  - mixed 340
  - simple 340
- ***Ethyl*** butyrate 365
  - acetate 365
  - sulphide 343
  - the radical 317
  - urea 332
- ***Ethylamine*** 343
- ***Ethylene*** 383
  - diamine 356
  - glycol 351, 354
- ***Ethylic*** alcohol 338
  - aldehyde 350
  - ether 340
  - ether, continuous process for 340
  - mercaptan 343
  - nitrate 342
  - nitrite 342
- ***Ethylidene*** dibromide 353
  - dichloride 353
  - dimethylate 353
  - ethylate 353
  - the radical 353
- ***Ethyl*** iodide 318
- ***Euclase*** 234
- ***Euxenite*** 236
- ***Evaporation,*** spontaneous 105
- ***Explosive*** character of nitrogen chloride 121

F

- ***Fats*** and oils, composition of 368
- ***Fatty*** acids, series of 358, 359
- ***Feculæ,*** starch 373
- ***Feldspar*** 231, 234
- ***Fermentation*** 325
  - acetic 360
  - lactic 356
  - vinous 339
- ***Ferric*** chloride 288
  - oxide 287
  - sulphate 288
- ***Ferrocyanogen*** 328
- ***Ferroso-ferric*** oxide 287
- ***Ferrous*** chloride 288
  - oxide 287

PAGE

- ***Fibrin*** 403, 404
- ***Fibrous*** fracture 179
- ***Fire*** damp 334
  - extinguisher, use of carbonic acid in 160
- ***Fixing*** of photographic prints 197
- ***Flame,*** nature of 162
- ***Flint*** 169
- ***Florence*** flask, description and uses of 81
- ***Flower-pots,*** composition of 235
- ***Flowers*** of sulphur 103
- ***Fluorescence*** of fluor-spar 219
- ***Fluorine*** 82
  - principal source of 82
  - properties of 82
- ***Fluor-spar*** 82, 219
  - crystalline forms of 60
- ***Formates*** 360
- ***Formic*** acid 359
  - acid, properties of 360
- ***Formulæ,*** chemical 28
  - empiric 32
  - empirical 314, 318
  - graphic 32
  - rational 318
- ***Formyl*** trichloride 357
- ***Fractional*** distillation 327, 335
- ***Fulminating*** gold 205
- ***Funnel-tube,*** description and use of 70
- ***Furnace*** for organic analysis 312
  - puddling 285
- ***Fusel*** oil 339
- ***Fusible*** alloy of bismuth 145
- ***Fusibility*** of metals, table of 177

G

- ***Gadolinite*** 236
- ***Galena*** 221
- ***Gallic*** acid 395
- ***Gallium*** 295
  - chloride 296
- ***Galls,*** nut 395
- ***Galvanized*** iron 247
- ***Garnet,*** crystalline form of 59
  - noble 234
- ***Gas,*** illuminating, manufacture of 165
- ***Gaseous*** molecules, volume of 50
- ***Gasoline*** 335

PAGE

- ***Gay*** Lussac, laws of ... 48
- ***Gelatines*** ... 403
- ***Gelatinous*** silica ... 168
  - tissues ... 403
- ***German*** silver ... 178
- ***Glacial*** acetic acid ... 360
  - phosphoric acid ... 136
- ***Glass,*** common bottle ... 170
  - crown ... 170
  - etching on, by hydrofluoric acid ... 83
  - flint ... 170
  - how colored ... 170
  - manufacture of ... 170
  - plate ... 170
- ***Glauber's*** salts, crystalline form of 62
- ***Glaze*** for china ... 235
  - for earthenware ... 235
  - for stoneware ... 235
- ***Globulin*** ... 404
- ***Glucinum*** chloride ... 236
  - derivation of name ... 236
  - mineral sources of ... 235
  - or beryllium ... 235
  - oxide ... 236
- ***Glucose*** ... 371
  - manufacture of ... 371
  - natural sources of ... 371
  - properties of ... 372
  - varieties of ... 372
- ***Gluten*** casein ... 404
- ***Glycerine*** ... 366
  - derivatives of ... 368
  - production of ... 367
  - properties of ... 367
- ***Glyceryl*** ... 357, 366
  - trichloride ... 368
- ***Glycol*** diacetate ... 356
  - diethylic ... 356
  - ethylene ... 351
  - monethylic ... 356
  - propylene ... 351
- ***Glycolic*** acid ... 355
- ***Glycols*** ... 351, 354
  - series of ... 355
- ***Gold*** ... 203
  - alloys of ... 205
  - assaying of ... 205
  - carat of ... 205
  - fulminating ... 205
  - leaf ... 204
  - leaf, transparency of ... 204

PAGE

- ***Gold,*** monoxide ... 205
  - native ... 204
  - natural crystals of gold ... 203
  - nuggets of ... 203
  - occurrence in nature ... 203
  - protochloride ... 205
  - properties of ... 204
  - salts, characteristics of ... 205
  - trichloride ... 205
  - trioxide ... 205
- ***Graham's*** dialyser ... 169
- ***Granular*** fracture ... 179
- ***Graphic*** formulæ ... 32
- ***Graphite,*** artificial ... 152
  - or plumbago ... 151
  - uses of ... 152
- ***Gray*** cast-iron ... 284
  - copper, crystalline form of ... 59
- ***Green*** fire ... 215
  - vitriol ... 288
  - vitriol, crystalline form of ... 62
- ***Greenockite*** ... 249
- ***Grotto*** del Cane ... 158
- ***Gum-arabic*** ... 374
  - benzoin ... 393
  - tragacanth ... 375
- ***Gums*** ... 374
- ***Gun*** cotton ... 374
  - metal ... 178
- ***Gunpowder,*** manufacture of ... 187
- ***Gypsum*** ... 220

H

- ***Hæmatite,*** brown ... 282
  - red ... 282
- ***Hardening*** of steel ... 287
- ***Hardness*** of metals ... 175
- ***Heat,*** influence of, on affinity ... 19
- ***Heavy*** spar ... 212
  - stone ... 305
- ***Hemihedral*** modification ... 57
- ***Hemlock,*** poisonous ... 401
- ***Hemoglobin*** ... 404
- ***Heptyl*** hydrate ... 336
- ***Heptylic*** alcohol ... 336
- ***Hexyl*** hydrate ... 336
- ***Hexylic*** alcohol ... 336
- ***Hippuric*** acid ... 394
- ***Hoffman's*** violet ... 393
- ***Holohedral*** modification ... 57

PAGE

Homologous series 320, 333
Hornblende 243
Horn silver 197
Hyacinth 239
Hydrates, acid 94
  basic 94
  monobasic, dibasic, etc 94
Hydraulic mortar 218
Hydrobromic acid 80
Hydrochloric acid bulb 314
  acid, chemical properties of 79
  acid, occurrence in nature 78
  acid, physical properties of 78
  acid, preparation of 78
Hydrocyanic acid, properties of 327
Hydroferrocyanic acid 328
Hydrofluoric acid 82
Hydrogen 69
  and oxygen, explosive mixture of. 73
  arsenide 138
  arsenide, frightfully poisonous character of 138
  bromide 80
  burning in air, products of 74
  chemical properties of 73
  flame, sounds caused by 74
  fluoride 82
  in meteorites, sources of 72
  occlusion of 72
  occurrence of 69
  phosphide 133
  phosphide, preparation and properties of 133
  physical properties of 71
  preparation of, by metallic sodium 71
  preparation of, by zinc 70
  sulphide 106
  sulphide, properties of 107
Hydroxybenzol 390
Hygrometer, use of 96
Hypobromous acid 99
Hypochlorous oxide 98

I

Ignition, definition 162
Immediate principles of organic compounds 311
Indigo 391
  how to dye with 391

PAGE

Indigo, insoluble 391
  soluble 391
Indium 295
  chloride 295
  oxide 295
  salts, characteristic property of 295
Ink, black, how formed 289
  stains, how removed 369
Iodic oxide 99
Iodine 80
  occurrence in nature of 80
  preparation of 80
  properties of 81
  test for 81
  tincture of 81
Iodoform 358
Iridium 269
  carbide 270
  oxides 270
Iron 282
  alum 234
  bloom 285
  cast 284
  cold- and red-short 285
  galvanized 241
  magnetic oxide of 287
  monosulphide 288
  monoxide 287
  pig 284
  principal ores of 282
  pyrites 288
  pyrites, crystalline form of 59
  pyrites, magnetic 288
  pyrites, white 288
  refining of 284, 285
  rust 287
  salts, characteristics of 288
  sesquioxide 287
  specular pig 284
Isomeric bodies 319
Isomerism 319
Isomorphism, definition of 64

J

Jasper 168
Java, poison valley of 158

K

Kelp 81
Ketone 337, 350, 354

PAGE

- ***Kinetic*** energy 161
- ***Kupfer*** nickel 293

L

- ***Labradorite*** 234
- ***Lactic*** acid 355
  - fermentation 356
- ***Lactose*** 372
- ***Lamp-black*** 152
  - manufacture of 153
- ***Lanthanum*** 238
  - oxide 238
- ***Lapis*** lazuli 234
- ***Law*** of definite proportions 24
  - of multiple proportions 26
- ***Laws,*** Dalton's 24
  - Gay Lussac's 48
- ***Lead*** acetate, neutral 362
  - carbonate 224
  - chloride 223
  - chromate 224, 303
  - diacetate 362
  - glaze 223
  - iodide 223
  - metallurgy of 221
  - monoxide 222
  - nitrate 224
  - oxide of 222
  - oxychloride 223
  - pencils, manufacture of 152
  - plaster 367
  - poisoning 225
  - principal ore of 221
  - properties and uses of 222
  - salts, characteristics of 225
  - sulphate 224
  - tungstate 305
- ***Legumin*** 404
- ***Lepidolite*** 193
- ***Levulose*** 372
- ***Libavius***, fuming liquor of 276
- ***Liebig's*** method of organic analysis 311
  - potash bulb 312
- ***Light,*** influence of, on affinity 20
- ***Lime*** light 96
  - milk of 217
  - water 217
- ***Limes,*** fat 218
  - poor 218
- ***Limestone*** 216
- ***Limonite*** 282
- ***Linnaite*** 293
- ***Liquation*** of tin 274
- ***Liquid*** sulphurous oxide, preparation of 109
  - sulphurous oxide, properties of 109
- ***Litharge*** 222
- ***Lithia*** mica 193
- ***Lithium*** 193
  - alum 234
  - salts, characteristics of 193
- ***Litmus*** paper, blue, use of 79
- ***Luminous*** calcium paint 219
  - paint, barium 213
- ***Lunar*** caustic 197
  - caustic, antidote for 198
- ***Lustre,*** metallic 175
- ***Lyon's*** blue 393

M

- ***Magnesia,*** calcined 244
  - white 244
- ***Magnesite*** 244
- ***Magnesium*** 243
  - bromide 244
  - carbonate 244
  - chloride 244
  - hydrate 244
  - iodide 244
  - oxide 244
  - salts, characteristics of 245
  - sulphate 244
- ***Magnetic*** iron pyrites 288
- ***Magnetite*** 287
- ***Malachite*** 256
- ***Malic*** acid 370
- ***Malleability*** of metals 176
  - of metals, order of 177
- ***Malt*** 339
- ***Maltose*** 372
- ***Manganates*** 290
- ***Manganese*** 289
  - alum 234, 291
  - black oxide of 290
  - carbonate 291
  - compounds of with oxygen 289
  - dioxide 290
  - monoxide 290
  - oxide 290

PAGE

- ***Manganese*** peroxide 290
  - salts, characteristics of 291
- ***Manganic*** acid 290
  - sulphate 291
- ***Manganous*** sulphate 291
- ***Margaric*** acid 364
- ***Marl*** 234
- ***Marsh's*** test for arsenic 139
- ***Mass,*** blue 253
- ***Massicot*** 222
- ***Matter*** 13
  - indestructibility of 24
- ***Melaconite*** 258
- ***Melissylic*** palmitate 366
- ***Mercaptans*** 342
- ***Mercurial*** palsy 253
- ***Mercuric*** chloride 254
  - iodide 255
  - nitrate 256
  - oxide 253
  - sulphate 255
  - sulphide 254
- ***Mercurous*** chloride 253
  - iodide 255
  - nitrate 256
  - oxide 253
  - sulphate 255
- ***Mercury*** 251
  - cyanide 328
  - extraction of 252
  - gray oxide of 253
  - properties of 252
  - red oxide of 253
  - salts, characteristics of 256
  - suboxide 253
- ***Metaarsenic*** acid 140
- ***Metallic*** fractures 179
  - lustre 175
  - oxides, how reduced 178
  - powders, lustre developed by rubbing 175
  - sulphide, how reduced 178
- ***Metals*** of alkaline earths 211
  - of the earths 230
  - fusibility of, tables 177
  - general method of extraction from ores 178
  - general properties of 175
  - hardness, brittleness of 175
  - of platinum group, characteristics of 266

PAGE

- ***Metals,*** specific gravity of, tables. 177
- ***Metameric*** bodies 319
- ***Metamerism*** 319
- ***Metaphosphoric*** acid 136
- ***Meteorites,*** occluded hydrogen in 72
- ***Methane*** 334
- ***Methylamine*** 318
- ***Methyl*** acetate 365
  - butyl 318
  - bromide 336
  - chloride 336
  - ethyl 318
  - hydrate 336
  - iodide 318, 336
  - nonyl-ketone 354
  - phenyl 392
  - phosphine 344
  - propyl 318
  - the radical 317
  - urea 332
- ***Methylic*** alcohol 336
  - aldehyde 350
  - ether 350
  - nitrate 342
- ***Mica*** 234
- ***Milk*** of lime 217
  - sugar 372
- ***Minium*** or red lead 322
- ***Molasses*** 372
- ***Molecular*** formulæ, determination of 314
  - structure 30
  - weight 51
  - weight, determination of 315
- ***Molecule,*** atomic grouping in 30
  - chemical 30
- ***Molecules,*** actual size of 51
  - compound 16
  - definition and general views of 15
  - elementary 15
- ***Molybdenite*** 304
- ***Molybdenum*** 304
  - anomalous quantivalence of 303
  - chlorides 305
  - oxides 305
- ***Molybdic*** ochre 304
- ***Monad*** element, definition of 31
  - metals, classification of 179
- ***Monadic*** type, non-metallic elements 69
- ***Monethylic*** glycol 356

PAGE

Monobromo-benzol 389
Monometric system of crystals 58
Morphine 401
Mortar, hydraulic 218
Mortars 217
Mother of vinegar 362
Mucilage 375
Murexide 371
Myosin 404

N

Naphtha 335
Naphthalene 396
Narcotine 401
Nascent state 110
Natural nitrates, origin of 127
Nickel 293
  ammonium sulphate 294
  chloride 294
  glance 293
  monoxide 294
  ores of 293
  oxide 294
  peroxide 294
  potassium sulphate, crystalline form of 62
  salts, characteristics of 294
  sesquioxide 294
  sulphate 294
  sulphate, crystalline form of 60
  sympathetic ink 294
  vitriol 294
Nicotine 401
Night green 393
Nightshade, the deadly 402
Niobium 207
  former name of 208
  metallic properties of 208
  sources of 207
Nitric acid 127
  acid, experiments with 128
  acid, occurrence in nature 127
  acid, preparation of 127
  acid, properties of 128
Nitro benzol 389
Nitrogen 118
  and oxygen, compounds of 123
  anhydride 126
  chloride 121
  determination of, in organic compounds 313

PAGE

Nitrogen, dioxide 125
  dioxide, experiment with 119
  dioxide, general properties of 119
  dioxide, how obtained pure 125
  dioxide, preparation of 125
  dioxide, properties of 126
  in atmosphere, use of 97
  iodide 121
  monoxide 123
  monoxide, experiment with 124
  monoxide, liquefaction of 124
  monoxide, preparation of 123
  monoxide, uses of 123
  occurrence and preparation of 118
  pentoxide 126
  peroxide 126
  tetroxide 126
  trioxide 126
Nomenclature, chemical 42
Non-caking coal 155
Non-metallic elements, classification of 68
  elements, molecular types of 69
Nonyl hydrate 336
Nonylic alcohol 336
Nordhausen sulphuric acid 113
Nuggets of gold 203
Nut-galls 395

O

Occlusion, definition of 72
  of hydrogen 72
Octyl hydrate 336
Octylic alcohol 336
Œnanthic aldehyde 353
Oil of bitter almonds 392
  of garlic 384
  of mustard 384
  of rue 354
  of vitriol 113
  of winter-green 395
Oils, extraction of 369
  the essential 395
Olefines 382
  group of 383
Oligoclase 234
Opium 401
Organic chemistry, scope of 311
  compounds 310
  compounds, immediate principles of 311

PAGE
Orpiment 140
Orthite 238
Orthoarsenic acid 140
Orthoclase 234
Orthophosphoric acid 135
Osmiridium 270
Osmium 271
  tetroxide 272
Oxalic acid, antidote for 369
  acid, how obtained 369
  acid, properties of 370
  acid, uses of 369
Oxidizing cone of a flame 164
Oxides of metals, how reduced 178
Oxygen 87
  chemical properties of 89
  derivation of name 87
  experiments with 90
  in atmosphere, uses of 97
  preparation of, from mercuric oxide 88
  preparation of, from potassium chlorate 88
  physical properties of 89
  slow combustion by 90
  use of, in respiration 91
  wide diffusion of 87
Oxyhydrogen blowpipe 95
Ozone 91
  molecular constitution of 92
  preparation and properties of 91

P

Palladium 269
  metallic, useful property of 269
Palmitic acid 359
  aldehyde 353
Palsy, mercurial 253
Paraffine radicals, trivalent 357
Paraffines 333
  solid, obtained from coal-oil 335
  substitution compounds of 336
Paris violet 393
Pearl white 144
Pectin, or fruit jelly 375
Pelargonic acid 364
Pepsin 404
Perbromic acid 99
Periodic oxide 99
Perissad elements, table of 83
  metals, classification of 179

PAGE
Peruvian bark, source of quinine 390
Petroleum 334
Pewter 178
Phenol 390
Phenyl hydrate 390
Phlorglucin 390
Phosgenes 343
Phosphines, primary 343
  secondary 344
Phosphonium iodides 343
Phosphor bronze 274
Phosphoretted hydrogen 133
Phosphoric acid 135
  acid, glacial 136
Phosphorus 130
  allotropic modifications of 131
  and oxygen, compounds of 134
  commercial, production of 131
  experiments with 132
  occurrence in nature of 130
  pentoxide 134
  preparation of 130
  properties of 131
  trichloride 135
  trioxide 134
Photographic negative 197
  process 197
  silver print 197
Physics, definition of 14
Picric acid 391
Pig iron 284
Pitchblende 306
Plaster of Paris 220
Platinic oxide 269
Platiniridium 270
Platinous oxide 269
Platinum 266
  black 268
  chlorides 268
  extraction of 267
Plumbago, or graphite 151
Plumber's solder 178
Pneumatic trough, description and use of 70
Polymeric bodies 319
Polymerism 319
Porcelain 234
Potash bulb, Liebig's 312
Potassium 184
  acetate 360
  acid carbonate 188

PAGE

Potassium acid sulphate 187
- acid tartrate 370
- bromide 186
- carbonate 188
- chlorate 187
- chlorate, experiments with 188
- chlorate, use of, in preparation of oxygen 88
- chloride 186
- cyanate 33
- cyanide 328
- dichromate 303
- ferricyanide 329
- ferrocyanide 328
- ferrocyanide, crystalline form of 60
- fluoride 186
- hydrate 185
- iodide 186
- manganate 290
- metallic, properties of 185
- monoxide 185
- neutral carbonate 188
- neutral chromate 303
- nitrate 186
- permanganate 290
- preparation of metallic 184
- salts, tests for 188
- sulphate 187
- sulphate, crystalline form of 61
- sulphides 186
- sulphocyanate 331
- sulphocyanide 331
- sulphocyanide, experiments with 331

Potential energy 161

Pottery 234

Precipitations of aqueous vapor, forms of 98

Propane 334

Propionic acid 362

Proportions, definite, law of 24
- multiple 26

Proprionic acid, derived from acrolein 352

Propylamine 318

Propylene 383, 384
- glycol 351, 354

Propyl hydrate 336
- the radical 317

Propylic aldehyde 350

Propyl iodide 318

Protein substances 402

PAGE

Prussian blue 329

Puddling furnace 285
- of iron 285

Putrefaction 321

Putrefactive decay 321

Pyroarsenic acid 140

Pyrolusite 290

Pyrophosphoric acid 136

Pyroxene 234

Q

Quadrivalent element, definition of 31

Quantivalence, apparent and real 230
- definition of 31
- influence of, on molecular structure 40
- of metals of the earths 230
- of the radicals 40
- representation of 31
- tables of 33, 34

Quartz, crystalline form of 64

Quick vinegar process 361

Quicklime 217

Quinine 401

Quinone 392

Quinquivalent element, definition of 31

R

Radicals, compound 93
- organic 317
- quantivalence of 40
- simple 39

Raw sugar 372

Reactions, chemical 28

Realgar 140

Red hæmatite 282
- lead or minium 223
- precipitate 253
- prussiate of potash 329
- short iron 286

Reducing flame 164

Refining of sugar 372
- of sulphur 103

Reinsch's test for arsenic 140

Rennet, property of 404

Replacement, theory of 38, 317

Respiration, use of oxygen in 91

Rhigolene 334

PAGE
Rhodium 270
  gold 270
  oxides 271
Rhombohedron, derivation of 64
Roll sulphur 104
Rosaniline 392
Rouge 287
Royal water 129
  water or aqua regia 129
Rubidium 194
  alum 234
  general properties of 114
Ruby 232
Rust, iron 287
Ruthenious chloride 271
Ruthenium 271
  oxychloride 271
  tetroxide 271
Rutile 276

S

Saccharose 372
Safety-lamp, cause of failure of 165
  Davy 164
Sal-ammoniac 122
  experiment with 122
Salicyl hydride 394
Salt, common 190
  common, curious crystals of 190
Saltpetre 186
Salts, definition of 41
  deliquescence of 95
  efflorescence of 95
  nomenclature of 44
Samarskite 237
Sand-blast process, description of 83
Sapphire 232
Scale, boiler 94
Scapolite 234
Scheele's green 140
Selenious oxide 114
Selenite 220
Selenium 114
  properties of 114
  source of 114
  valuable electrical property of 114
Semi-bituminous coal 155
Septivalent element, definition of 31
Sexivalent element, definition of 31
Siderite 282

PAGE
Silesian process for reduction of zinc 246
Silica 168
  gelatinous 168
Silicate soap 368
Silicic acid 168
Silicon 166
  bromide 161
  chloride 167
  dioxide 168
  fluoride 168
  hydride 167
  iodide 168
  modification of 166
  occurrence in nature 166
Silver 194
  alum 234
  amalgamation process for 195
  assaying of 196
  bromide 197
  chloride 197
  iodide 197
  metallic, properties of 196
  metallurgy of 195
  nitrate 198
  nitrate, antidote for 198
  occurrence in nature 194
  oxide 197
  photographic prints 197
  salts, experiments with 198
Simple displacement, gases collected by 76
Smithsonite 245
Snow crystals 93
Soap, manufacture of 367
  pure, how obtained 367
  why it cleanses 368
Soaps, cheap 368
  hard 367
  soft 367
Soapstone 243
Sodium 189
  acetates 360
  acid sulphate 192
  alum 234
  bicarbonate 192
  carbonate 191
  carbonate, Leblanc's process for 191
  chloride 190
  hydrate 189
  metallic, how prepared 189

PAGE
Sodium, metallic, properties of 189
  monoxide 189
  neutral sulphate 192
  nitrate 193
  nitroferrocyanide 330
  peroxide 189
  phosphates 192
  pyro-borate 192
  salts, detection of 193
  salts, experiment with 193
  tetra-silicate 192
  uranate, uses of 306
Solder, plumbers' 178
Soluble starch 374
Solution, influence of, on affinity 19
Sombrerite 130
Spaces, inter-atomic 17
  molecular 17
Specific gravity of metals, table of 177
  identity 13
Spectroscope, construction of 194
Specular iron ore 282
Speculum metal 178
Speiss cobalt 291
Spiegel pig-iron 284
Spirits of nitre 342
Spitting of molten silver 196
Springs, mineral 94
Stable compounds 18
Stannic acid 275
  chloride 276
Stannous chloride 276
Starch 373
  feculæ 373
  granules 373
  solution, use of, as test for iodine 81
Stearic acid 364
  aldehyde 353
Steel, Bessemer process for 286
  hardening and annealing of 287
  manufacture of 286
Stibnite 143
Stoneware 235
Stream-tin 273
Strontianite 214
Strontium 214
  carbonate 215
  chloride 215
  dioxide 215
  monoxide 215
  nitrate 215

PAGE
Strontium red fire 215
  salts, characteristics of 215
  sulphate 215
Structure, molecular 30
  of organic bodies 315
Strychnine 401
Sublimation, definition of 81
Substances 13
  compound 14
  definite, composition of invariable 24
  elementary 14
Substitution, theory of 38, 317
Substitutions in trivalent paraffine radicals 357
Sugar, beet 372
  cane 372
  maple, use of 372
  of milk 372
  raw 372
  refining of 372
Sulphide of metals, how reduced 178
Sulphur 103
  allotropic modifications of 104
  changes during the liquefaction of 106
  chemical properties of 106
  crystalline form of 61
  experiments with 106
  flowers of 103
  physical properties of 104
  refining of 103
  roll 104
  sources of 103
Sulphuric acid, experiments with 113
  acid, fuming 112
  acid, Nordhausen 112
  acid, preparation of 111
  acid, properties of 113
  acid, test for 113
  oxide 110
Sulphurous acid 107
  oxide 108
  oxide, liquefaction of 109
  oxide, physical properties of 108
Sweet spirits of nitre 342
Symbols, atomic 27
  atomic, table of 29
Synthesis, definition of 20, 30
  of organic compounds 310
  of water 92

T

PAGE

Talc 243

Tannin 395

Tantalum 208

  occurrence of 208

  preparation and properties of 208

Tartar emetic 370

Taxidermy, use of arsenic in 140

Telephote, use of selenium in 114

Telluric dioxide 115

Tellurium 114

  derivation of name of 115

  properties of 114

Tempering, process of 287

Tenacity of metals 175

Terbium 237

  oxide 237

  sulphate 237

Terpenes 395

Test-tube, description of 88

Tetradic type, non-metallic elements 69

Thallium 206

  alum 234

  derivation of name of 206

  hydroxide 207

  monoxide 206

  preparation of 206

  properties of 206

  trioxide 206

Thebaine 401

Theine 402

Theorem of Avogadro 49

Theory of substitution 38

Thio-alcohols 342

Thorite 236

Thorium, properties of 236

  sources of 236

Tiles, composition of 235

Tin 273

  butter of 276

  "cry of" 274

  dioxide 275

  disulphide 275

  monoxide 275

  ore, sources of 273

  plate 274

  salt 276

  salts, characteristics of 276

  -stone 273

  -white cobalt 291

PAGE

Tincal 192

Tincture of iodine 81

Tinctures, nature of 338

Titanium 276

  dioxide 276

Toluidine 392

Toluol 392

Toning, photographic 198

Topaz 234

Tourmaline 234

Transparency of gold 204

Travertine 219

Tribromhydrin 368

Trichloraldehyde 352

Trichlorhydrin 368

Trichloride of gold 204

Triethylmethane 336

Triethylrosaniline 393

Triiodohydrin 368

Trimethene glycol 354

Trimethyl arsine 344

  phosphine 344

Trimethylethylammonium 343

Trimethylmethane 336

Trimetric system of crystals 60

Trinitrocellulose 374

Trinitroglycerine 368

Trinitrophenol 391

Triphenylrosaniline, hydrochloride of 393

Trivalent alcohol radicals, derivatives of 366

  element, definition of 31

Tungsten 305

  dioxide 305

  metallic, properties of 305

  mineral sources of 305

Turner's yellow 223

Turnbull's blue 330

Turpeth mineral 255

Type metal, composition of 142

Types, molecular, of non-metallic elements 69

  triadic molecular, non-metallic elements 69

U

Ultimate analysis of organic compounds 31

Ultramarine 234